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DEVELOPMENT, TEST AND EVALUATION OF THE ROCKET LAUNCHER SAFETY AND ARMING DEVICE (MLU-53/B)

By
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1 SEPTEMBER 1970

NOL

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

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DEVELOPMENT, TEST AND EVALUATION OF THE ROCKET LAUNCHER SAFETY AND ARMING DEVICE (MLU-53/B)

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ABSTRACT: The Rocket Launcher Safety and Arming Device (S&A), MLU-53/B, is a ram air turbine actuated safety and arming device which was developed for use in the ZAP weapon system. The S&A program fell into four production/test and evaluation phases. Testing in each of these phases revealed weaknesses which were corrected in the next production phase. The limited Phase IV (OPEVAL) testing done indicated that the MLU-53/B S&A device was a workable item. The S&A has passed all required environmental and safety tests including 1500g shock and HERO. The electrical and explosive out-of-line features of this S&A, combined with the superior environmental protection it affords the weapon initiating element, make it an important step toward a safer air launched weapon system.

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Development, Test and Evaluation of the Rocket Launcher Safety and Arming Device (MLU-53/B)

This report gives a history of the development, test, and evaluation of the Rocket Launcher Safety and Arming Device, MLU-53/B. The MLU-53/B was developed as a major safety component of the ZAP weapon system. All work was performed under AIR TASK A35-532/W1153.

Valuable contributions to this report were made by B. T. Cheeka, A. M. Corbin, N. L. Demas, S. L. Min, G. W. Peet, J. E. Salmon and The Marquardt Corporation.

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Captain, USN
Commander

R. E. GRANTHAM
By direction

CONTENTS

REFERENCE

(a) NOLTR 70-52, ZAP Phase III Test and Evaluation Report
(b) AS 1912H, Purchase Description, Safety and Arming Device, Rocket Launcher, MLU-53/B

ILLUSTRATIONS

TABLES

INTRODUCTION

1. This report deals with the development of the MLU-53/B Rocket Launcher Safety and Arming (S&A) Device and its evaluation by the U. S. Naval Ordnance Laboratory, White Oak (NOL). The MLU-53/B S&A was developed as a component of the ZAP weapon system. Its function is to maintain an explosive and electrical out-of-line condition of the motor initiating element (BBU-7/B Detonator) until an air speed of 230 ± 10 knots is obtained, at which point it arms the weapon. The S&A also returns to the safe position when a minimum of 195 knots is reached.

2. The development program and the test and evaluation program of the MLU-53/B were divided into four phases:

Phase I - Design Models and Tests
Phase II - Engineering Models and Tests
Phase III - Technical Evaluation Models and Tests
Phave IV - Operation Evaluation Models and Tests

PHASE I DESIGN CONSIDERATIONS AND CONTRACTOR TESTING

3. The Phase I development of the S&A device was carried out by The Marquardt Corporation (TMC) during March, April, and May of 1968. Design considerations were defined in the Description and Specification section of Contract N60921-68-C-0205 as listed in Appendix A.

4. The Phase I S&A device (TMC P/N X24450) is shown in Figures 1 through 6. This device was constructed to prove feasibility of the idea. This was accomplished by fabricating and testing the unit in the shortest possible time. All parts were completely machined from raw bar stock and tubing. The primary material was aluminum; exceptions being the rotor, MDF block, turbine shaft, and certain standard parts such as bearings, screws, and pins, which were steel. The four major subassemblies making up the unit were:

a. The turbine assembly which included the turbine and shaft, the flyweights, bearings, and the rounded nose which contained the other parts.

b. The rotor-actuator assembly which consisted of a bar screw (linearly actuated by the turbine flyweights to produce a rotation of the detonator rotor), the detonator rotor, the arming circuit switches, a spring to provide the force to hold the rotor in the safe position, and the aft housing (which provided the inside wall of the turbine air passage in addition to housing the other elements).

c. The shroud assembly which supported the entire mechanism and formed the outer wall of the air passage as well as the mounting flange.

d. The MDF block which had gas passages which lined up with the detonators when the S&A was armed, and also had four convergent-divergent nozzles to control and limit the turbine air velocity and hence the turbine speed.

5. Contractor testing of the first two units commenced on 28 April 1968. Initial tests consisted of arming the units by simulating air speeds from 0 to 600 knots at near sea level conditions. First test runs indicated that the S&A was arming and disarming at air speeds approximately 60 knots too high. Test unit number one (TU-1) was modified to lower the actuation air speed by reducing the spring preload. Subsequent tests revealed that this objective was met. Test unit number two (TU-2) was modified by increasing the flyweight mass and modifying the exit nozzle configuration slightly. Tests on unit number two following modifications also indicated that the objectives were met (see Table 1). The flyweight and nozzle modifications were selected for the 20 S&A units for delivery since this could be accomplished within a shorter period of time. Calibrations on the 20 units indicated a slight additional trimming might be necessary, but for lot number one, the calibration was adequate.

6. The two test units were subjected to endurance tests and cold temperature tests. Endurance testing consisted of operation simulating 450 KIAS at approximately sea level, with a return to zero speed condition at periods of 20 to 30 minutes. Data taken during the 20-hour life test showed an arm/disarm switch point scatter of about 15 knots. TU-2 was removed from the test cell after 12 hours of test time for photographs. When the unit was reinstalled, it failed to switch to the armed condition. Disassembly revealed that at least one of the bearings in the turbine assembly was contaminated. After a few minutes, the bearing seemed to function properly again. The unit was reassembled and returned to test, where it armed normally. However, after about 15 seconds at 350 knots, it suddenly disarmed. Inspection of the turbine assembly again indicated contamination.

7. TU-1 was soaked at -65°F, and then tested at sea level wind tunnel conditions. The cold soak resulted in an increase in the arming speed of about 60 knots. This was considered to be a result of viscosity changes in the bearing lubricant. Two silicone base lubricants were tested at room temperature and -55°F. Dow-33 silicone grease showed a shift of only six knots while Dow FS-1292 shifted the arm point by 30 knots. These lubricants were tested only to determine the minimum amount of shift that could be expected. A third test was run using sealed bearings lubricated with light instrument oil. The test data showed a shift of about 50 knots between 70° and -55°F which seems to be a normal shift for most lubricants regardless of their initial viscosity. The test data for various lubricants, shown in Figure 7, indicate that temperature will change the initial arming point by about 50 knots/100°F. It should be noted that the silicone base lubricants have a limiting upper speed which for this unit was 15,000 rpm (about 350 knots). Beyond this point, lubricating value deteriorates rapidly, and bearing life is in jeopardy.

PHASE I TEST AND EVALUATION BY NOL

8. Twenty Phase I units were received at NOL in May 1968. Table 2 lists the serial numbers, and the air pressure differential across the S&A to cause arming and disarming as determined by TMC.

9. Fourteen of these twenty units were subjected to a preliminary evaluation program as shown in Figure 8. Test descriptions are given in Appendix B with a summary of results given in Table 3. The major discrepancies revealed in this test program were:

a. Average of 40 knots difference between NOL's and TMC's arm and disarm velocity measurements.

b. Rotation of the rotor and loosening of three out of four of the MDF block mounting screws on one unit in high frequency vibration.

c. Contamination of the turbine ball bearings in salt spray, and temperature and humidity.

d. Shattering of the arming micro switches in forty-foot guided drop.

e. Rotation of one rotor in the safety shock test.

f. Loosening of the balance weight during an endurance test.

10. The only discrepancy which caused great concern was the difference in NOL and TMC data on arming and disarming air speeds. This problem was attributed to the following items:

a. TMC used the speed of sound at ambient conditions to compute the air speed in their test cell. Since the speed of sound is a function of the temperature of the air, its speed would be different inside the cell where the air temperature is other than ambient. Assumption of a constant speed of sound would lead to errors in air speed calculations.

b. Airflow around NOL's simulated launcher inside the wind tunnel introduced an entrance effect which would require a higher air speed. TMC's test cell was simply a pressure tube the same diameter as the S&A device, thereby causing no entrance effects.

c. TMC tests were performed at sea level, whereas NOL tests were conducted at an equivalent altitude of 3,000 feet. At this altitude, the air speed required to turn the turbine was estimated from Figure 9 to be 15 knots higher than that required at sea level. This shift is due to reduced air density with increased altitude.

d. It was felt that there was some incompatibility in the procedure for increasing the test cell/wind tunnel air speeds during tests. If this were done too rapidly, the slowly responding turbine would appear to arm at a lower speed.

Other discrepancies resulted in design change recommendations as follows:

a. A positive stop be provided so that the rotor could not override.

b. The rotor be fastened more securely to the actuator shaft to prevent its turning on the shaft and be keyed to the shaft to prevent misassembly.

c. The micro switches be replaced by a rotary switch to eliminate breakage in rough handling.

d. The shielded turbine bearings be replaced by sealed bearings to prevent failure due to contamination.

PHASE II DESIGN CONSIDERATIONS AND CONTRACTOR TESTING

11. The design of the Phase II S&A device was initiated in April 1968, with a study conducted to establish all specification and interface requirements not previously defined. As a result of that study the following design features were incorporated:

a. Sealed rotary switches to replace the Phase I micro switches.

b. An integrated detonator rotor and MDF block designed to increase environmental resistance.

c. A positive out-of-line feature which physically prevents the misassembly of the rotor and MDF block.

d. A locking feature to keep the S&A in the safe position under high acceleration loading in the axial direction.

e. Use of castings, powdered metal parts and extrusions to minimize the number of parts required and the number of machining operations.

12. Test Unit 2 was modified to evaluate a new nozzle design which was made necessary by an NOL change in aft end requirements. The new nozzle design changed the circular Phase I nozzles to a modified rectangular nozzle. Initially, the nozzle areas were the same as Phase I units, but subsequently, the throat and exit areas were increased by 20% to provide a reasonable arming speed with a spring preload of approximately 100 pounds.

13. The Phase II S&A device was designed into three separate modules to facilitate the manufacturing and fabrication process. Each module was to be completely interchangeable and reuseable (see Fig. 10). These modules were capable of being fabricated in parallel to reduce total manufacturing time. Significant features of each module are listed below:

a. TURBINE ASSEMBLY (see Fig. 11). Since the Phase I turbine assembly met the design requirements for the S&A, the only modification required was a material substitution. The turbine housing was changed from a hogout version to a die casting. The bearing retaining nut was die cast net with the thread and airfoil contour included. The turbine wheel was investment cast with 431 CRES steel substituted for aluminum to increase the foreign object ingestion capability of the blades. Flyweight arms were made of extruded stock to eliminate contour milling. The turbine balance ring was made as a powdered metal part which was formed net.

b. ACTUATOR ASSEMBLY (see Fig. 12). The actuator assembly was designed to cluster functionally related parts in a common housing. The housing was die cast to eliminate much of the machining. A gimbal assembly was designed to support the bar screw nut and eliminate binding of the bar screw during actuation. All linear actuator materials were changed from steel to aluminum.

c. DETONATOR ROTOR AND NOZZLE ASSEMBLY (see Fig. 13). A major redesign was required in the detonator rotor and nozzle assembly as a result of development testing and added functional requirements. A rotary switch replaced the micro switches, and the mild detonating fuze block was relocated to a position coplanar with the aft end of the assembly. Safe lock and inertial lock features were incorporated to insure safe handling of the unit. The entire detonator rotor and rotary switch assembly was sealed to prevent contamination of switch parts. The nozzles were configured into the housing die to eliminate contour milling.

14. Full design release was completed by the end of June 1968. During July and August 1968, design testing by NOL on the rotor, detonator, and electrical circuits indicated a severe design inadequacy in the rotor assembly and rotary switch elements (see par. 21 for details). As a result, the Phase II program was stopped, except for six inert units to be delivered to NOL in early September. A substantial design study effort on alternate design approaches in the aft end of the S&A was initiated at NOL.

15. Most of the Phase II machined parts had been completed when the program was halted. Some of the fabrication problems encountered with the parts were as follows:

a. Tooling problems occurred on machining the flyweight arms, the ring bearing, and the gimbal ring, and on drilling the hole in the rotor shaft.

b. Difficulty was experienced in holding the close tolerances called for on the rotor shaft.

c. Difficulty was encountered in retaining the helicoil inserts in the tapped holes.

d. The turbine wheel investment casting required considerable development before bladeforms and cast surface conditions were satisfactory.

16. Magnetic particle inspection indicated cracks in the turbine wheel hub after final machining and passivation. A sectioned casting verified that the apparent cracking was initiated by surface porosity caused by a mold reaction. It was felt that this cracking problem could have been eliminated by altering the casting process, and by proper passivation during subsequent operations. However, the unpredictability of the heat treatment response of 431 CRES made this alloy undesirable. Therefore, 17-4 PH stainless steel was selected as a better material for the turbine wheel and the MDF block. Based on stress safety margins in the design, the 431 CRES turbine wheels were acceptable for Phase II development use.

17. A list of apparent assembly and performance discrepancies and action items shown in Table 4 was generated following fabrication and testing of eight units. Six of these units were forwarded to NOL for further evaluation. Arm and disarm pressures on these six units as determined by TMC are given in Table 5.

PHASE II TEST AND EVALUATION BY NOL

18. Upon receipt of the six units at NOL in September 1968, they were subjected to tests according to Figure 14. A synopsis of test results is given in Table 6. All tests are defined in Appendix B.

19. All units were installed in a simulated launcher central tube and mounted in the NOL number one wind tunnel. Air velocity was adjusted slowly until arming was indicated by monitoring the detonator electrical circuit. The air speed was then decreased until disarm occurred. This test revealed that the six units all armed at air speeds in excess of those called out in the purchase specification. Additional operational data were obtained in the captive flight test. The S&A was mounted in a dummy pod and flown on an F-4 aircraft. The detonator circuits were monitored with the circuit in Figure 15. Results are given in Table 7.

20. Major discrepancies revealed in the remainder of the program were:

a. Switch chatter was indicated during operation on the vibration table. The switches were monitored on the circuit of Figure 16. Deposits of foreign material were found on switch pads which were covered with solder.

b. The MDF block was dislodged from the S&A on the 40 foot aft-end-down drop.

c. The bar screw failed during shock testing. It was found to have been installed improperly, and all units were refitted to comply with the drawings.

21. Concurrent with the test program described above, additional testing on explosive components was performed. It was discovered that the detonator blast dislodged the detonator lead wires and shattered the circuit board on the rotor when configured as shown in Figure 13. From this test, two redesigned rotors evolved, configured as follows:

a. The detonators were rear loaded into first redesign rotor with the leads exiting through 1/16 inch holes in the front face. A retaining nut was used to hold the detonator in place. The rotor was also grooved for a piston ring to throttle gas flow from rear to front of the rotor and thereby keep the electrical contacts clean.

b. The second redesigned rotor was a split design with the parting plane located at the detonator base ends. The two pieces were held together by four #10-32 screws. The detonators were back loaded into the front section of the rotor through which the leads exited through individual holes inclined 60 degrees to the rotor axis. The printed circuit board was secured to the front face with EPON 933 adhesive and #0-80 screws. No piston ring gas check was incorporated in this design.

22. One sample of each of the above designs was fired. Redesign (a) showed bulging of the circuit board due to lead wire motion. However, the piston seal reduced contamination of the switch parts. Redesign (b) showed bulging of the circuit board due to gas leakage around the #10-32 screws, but no lead wire motion was evident.

23. The best features of both designs were incorporated into a third redesign. This rotor was a one-piece design with detonators loaded from the rear and secured with a ball-bearing stake. The electrical leads exited at 45 degrees to the rotor axis. The printed circuit board was made with 1/16 inch instead of 1/32 inch thick material and secured to the rotor front face by crimping rotor metal over its edges. The piston ring seal was also incorporated. Three aft assemblies were tested with this configuration resulting in qualified successes. One ear broke off each of two piston rings and the rotor support bulkheads were deformed considerably under the explosive loads. The lead wire insulation was extruded from the lead wire exit holes and protruded beyond the circuit board in some cases.

24. The rotor design in paragraph 23 was selected as the best solution to the problem with the following suggested changes to eliminate its shortcomings.

a. Fillets and radii on the piston ring ears to reduce stress concentration.

b. Ribs cast integral with the aft housing casting to reinforce the rotor support bulkhead.

c. Electrical insulation sleeving to which the potting adhesive around the detonator would adhere more readily.

25. In late 1968, high contractor costs and low project funds forced cancellation of the contract for technical evaluation hardware. It was decided instead that incomplete Phase II hardware remaining at TMC would be modified as necessary and used to support the Phase III program.

PHASE III DESIGN CONSIDERATIONS AND CONTRACTOR TESTING

26. With the reactivation of the S&A program at TMC in mid-October 1968, approximately half of the components in the rotor and nozzle assembly were obsolete. The rotory switch and rotor assembly were completely redesigned by NOL to eliminate the switch contamination and structural problems which had been encountered previously. The leaf spring electrical contacts were replaced by spring loaded "pogo" contacts to eliminate switch chatter. The rotor and nozzle housing and the MDF block castings required significant rework.

27. A limited amount of testing was done to compare operation of Phase II and Phase III designs during fabrication. Turbine speed calibrations with a Phase II nozzle (0.150 inch throat) were run on both TU-3 and TU-4. Data from these tests are presented in Figures 17, 18, 19, and 20. A turbine speed calibration was also made on TU-4 with a die cast nozzle which had been machined from a 0.150 to 0.175 inch throat width. Test results with this modified nozzle are shown in Figure 21. This modification was anticipated to be a downstream method for arm-disarm trimming whether accomplished by a die change or a broach operation.

28. No significant fabrication or assembly problems were encountered with the Phase III S&A. Two hardware discrepancies which existed in the units as delivered to NOL were:

a. On six of the devices (S/N's 2019, 2021, 2024, 2025, 2027, and 2030) the bar screw nut was 1.00 inch rather than 0.820 inch long. Acceptance tests on these units insured that there was no interference during actuation.

b. A dimensional error in the rotor cavity of all the rotor and nozzle housing casting required machining such that the gap between the rotary switch ("pogo") contacts and the printed circuit board was reduced by 0.007 inch. Shortening of the gap produced an additional drag on the rotor due to higher contact spring force which in turn increased the differential between arm and disarm speeds of the S&A. Although schedule did not permit a recycle of the casting procurement to correct this discrepancy, it was corrected on the dies in anticipation of the next procurement.

29. All of the 24 S&A's delivered to NOL in Phase III were subjected to acceptance tests to determine the arm and disarm conditions. Prior to this, 22 of the units had been subjected to the same test using one Phase II rotor and nozzle assembly for all (the Phase II nozzle was 20 percent larger than the Phase III nozzle). Results of these tests are given in Table 8 from which the following are apparent:

a. A considerable amount of the differential in actuation speeds between units was caused by dimensional and spring preload tolerances. Since the data represent the "as fabricated" conditions with no shimming or component selection to bring performance to the nominal, the need for shimming to hold spring preload to much closer limits was indicated.

b. From these data and the turbine speed calibrations presented in Figures16 and 17, it can be shown that the ratio of flyweight force at arm to flyweight force at disarm was approximately six percent higher in Phase III units than on Phase II units. Most of this increase could be attributed to the force required to overcome the drag between pogo contacts and the printed circuit board. Mechanical interference in the actuator spring cavity was another possible source of friction.

PHASE III TEST AND EVALUATION BY NOL

30. No formal technical evaluation hardware was purchased from TMC. Rather, those Phase II units which had been contracted for before discontinuing manufacture were modified and redesigned as necessary and delivered to NOL with spare assemblies to facilitate reuse of devices. Hardware delivered in March and April 1969 included:

a. Ten complete inert S&A's.

b. Fourteen complete live-loaded S&A's.

c. Thirty live-loaded aft ends (arrived 3 March).

d. Twenty inert aft ends.

e. Thirty live-loaded rotors.

31. A summary of Phase III test results is given in Table 9. All of the problems exposed in this phase of evaluation were remedied as discussed below. Because schedules were very tight, the Phase IV contract was let before Phase III testing was completed. As a result some design changes were not incorporated in the release package in time to be reflected in Phase IV hardware. Results of this will be discussed in later sections. The remainder of this section deals with that testing which resulted in design changes.

32. On 4 March 1969, four of the used Phase II turbine and actuator assemblies were coupled with four live-loaded aft ends (item (c) above) and fired in the laboratory. Loaded MDF lines were coupled to each detonator for each shot. The MDF lines were cut in half for economy, with the realization that the firing train was not exactly as in the all-up system. This test was successful in all respects.

33. Shortly after the above firing tests, two successive failures of the fourth and last detonator occurred during attempted ripple firings in field tests at NWC, China Lake, California. A thorough laboratory investigation revealed several possible reasons for the

failures, but did not pinpoint the problem. It was discovered that the spline had slipped on the actuator shaft, throwing the rotor out of line in both cases. On one failure, the powdered metal balance ring had cracked, allowing the turbine shaft to move. Two design changes were proposed and incorporated in hardware on hand:

a. A locking device was incorporated on the arming shaft and rotor spline to eliminate possible out-of-line movement when rockets were fired.

b. The turbine balance ring was changed from powdered metal to a stronger machined steel piece.

34. A laboratory investigation was carried out on the ZAP Pressure Pulse Simulator (used to simulate the ZAP rocket blast pressures on the S&A). When the armed S&A was exposed to a blast impulse, the rotor first overrode the armed position, then rebounded and underrode. It was theorized that blast on the actuator slide caused the override, and the trapped gasses under the actuator caused the subsequent underride. To correct this problem, the detonator rotor and MDF block were modified and fitted with a positive stop in the armed position to prevent override. Four holes were drilled in the actuator slide to relieve any trapped gasses. These two alterations eliminated the rotor movement during rocket firings.

35. Nine inert Phase III units were sent to the wind tunnel to determine arming and disarming velocities. In every case, arming velocities were above specification requirements. Disarming velocities were likewise too high and also out of tolerance. Pressure arming data from Table 8 correlated reasonably well with the velocity data supplied by the wind tunnel. The principal reason for the high arming velocities was found to be the undersized nozzles. All units were modified to increase the nozzle size from 0.150 inch as delivered to 0.175 inch. A test of 11 corrected units showed that:

a. All units armed within the 230 ±20 KIAS at sea level requirement.

b. Two units disarmed below the 195 KIAS at sea level requirement.

The two failures were attributed to actuator spring preload errors caused by tolerance stack-up. A calibration program to insure uniformity of this preload was recommended to stabilize arm and disarm velocities in future lots.

36. In July 1969, three S&A units failed to disarm after firing of detonators and SMDC end caps. A slight torque applied to one unit caused it to disarm. Another disarmed when the indicator plate was tapped lightly. Examination of these three units plus two others which had not malfunctioned revealed several possible causes of the malfunction.

a. Eruption of the MDF block from a section of the inertial lock slot near the number four SMDC and cap caused drag on the rotor (see Fig. 22).

b. Contamination of the rotor seal ring by carbonaceous combustion by-products caused severe rotor drag.

c. Embossing of the thrust face in a cast rotor housing by a counterbore in the rotor thrust face caused rough bearing surfaces which tend to hang up (see Fig. 23).

37. Problem (a) was solved by milling away the portion of the inertial lock slot in the MDF block which erupted upon firing. This was possible, as the lock functioned on the other end of the slot. Problem (c) was solved temporarily by milling away a portion of the rotor housing thrust face and inserting a steel washer between the thrust surfaces to prevent the embossing process in the casting. Problem (b) proved a bit more difficult to remedy. At first, it was hoped that the seal ring could be omitted from the assembly. However, field tests showed metal particles large enough to short two detonators together were present in the switch cavity after firing one detonator. Hence, a new, fiber (Kulon "J") seal ring was obtained (shown in Fig. 24). This ring was shaped so that detonator/MDF line combustion pressures caused it to seal. After the gas pressure was relieved, the ring exerted very little force against the casting wall, allowing the rotor to turn freely. All of these fixes proved adequate in subsequent field testing.

38. As reuse of turbine and actuator assemblies was attempted, it became evident that contamination of the bearings was still a problem. Turbine bearings which had been exposed to rocket exhaust blast and then allowed to sit idle for a time rusted and seized or became rough. Units so affected could not be used in further tests without refurbishing due to their unreliable operating characteristics. Refurbishing amounted to replacing the two main turbine bearings and the actuator bearing and lubricating and freeing the flyweight bearings as necessary. After these steps were taken, the turbine assemblies worked as well as new.

39. With the realization that extensive reuse could not be made of the S&A's, the entire test and evaluation program was thoroughly reviewed. It was decided that unused S&A's were needed for system flight tests as long as they were available. Therefore, all S&A's were committed to support of system and safety tests for the remainder of the program, the laboratory component program being cancelled.

40. As the field test program proceeded at NWC, China Lake, and NATC, Patuxent River, more failures of the S&A to disarm occurred. In mid-October 1969, S&A S/N 2030, which had failed to disarm after three successive missions at NWC, China Lake, was returned to NOL in the armed condition. The unit had been thoroughly examined at NWC, China Lake, and had been given an operational check on the ground before each mission and worked properly each time. Upon disassembly at NOL, the actuator was found to be jammed. An attempt to

disassemble the actuator caused it to return to the safe position. Further examination revealed that the actuator failure resulted from deposition of plume debris in the actuator slide and bar screw area. Since this unit had been used to fire 16 rockets, cumulative degradation was thought to be a factor. Following this episode, two other S&A's failed in the same mode. This was interpreted as additional proof that the S&A as designed was a one-use item only.

41. Fairing fragments presented a problem late in this phase of the program. Although the turbine could "digest" any fairing fragments which reached it, some fragments jammed the S&A intake port and cut off the air supply. This condition was not considered to be a failure of the S&A, although it could prevent firing of any but the first rocket, as the S&A would disarm when air was severely reduced. A conical "screen" was placed over the air intake port on the pod to prevent fairing fragments from reaching the S&A.

42. Figure 25 shows the S&A mode indicator. The disk rotates 45 degrees with the rotor so that the slot exposes either a red background or a green background to indicate armed or safe mode respectively. After firing a rocket, the background was found to be burned too badly to be read. The problems encountered with this indicator prompted the suggestion from NWEF, Albuquerque, New Mexico, that a safe/arm indicator be devised that could be seen from the exterior of the pod and would not be damaged by the rocket blast. However, in view of the disarm problems encountered during field tests, there was reluctance to "hanging" an indicator fix on the S&A that could decrease the available disarm-return force. It was thought that any "quick fix" would create more problems than it would solve and only a long range solution was considered practical.

43. Since the S&A is a major safety component in the ZAP weapon system, it was subject to close scrutiny. System safety tests conducted by NWL, Dahlgren, Virginia, showed that the S&A was an effective safety device against both mechanical and radio frequency hazards. A full discussion of these tests is given in reference (a).

PHASE IV DESIGN CONSIDERATIONS, TEST AND EVALUATION

44. The hardware manufactured for Phase IV was substantially the same as that used in Phase III with changes in detail. A list of design changes which were to be included is given in Table 10. Since the units were contracted for before all of these changes could be documented, items (f) and (i) were not in the hardware as manufactured.

45. TMC reported several points of difficulty in building the Phase IV units. Among them were:

a. Inability to hold the turbine tip clearance in the turbine housing. Failure to hold this clearance resulted in an increase in arming speed.

b. Difficulty in obtaining the correct lubricant and radial clearance in the turbine ball bearings. Use of incorrect bearings would cause erratic turbine behavior.

c. Inability to obtain the five inch-ounce balance requirement on the turbine without increasing the size of the balancing hole out of tolerance.

d. Tendency of the "pogo" switch contacts to "plow" into the printed circuit material causing excessive drag on the rotor.

46. As part of the production requirement, TMC ran arm/disarm calibrations on all units. These data are presented in graphic form in Figure 26. Plotting the tolerance limits on Figure 26, one finds that all units disarm within the minimum limit. However, only about one half of the units meet the arming requirement.

47. In 1969, 126 complete S&A units were delivered to NOL. These units were put through the arm/disarm calibration on the NOL test set. Data from these calibrations are given in Figure 27. Comparison of Figure 27 and Figure 26 reveals a significant shift downward in arming speeds and a redistribution of disarming speeds. According to these results many more units were within the arming tolerance band, with about one half the units dropping below the minimum disarm point. This indicates a significant difference in either the methods or equipment used by TMC and NOL.

48. After the incoming calibration by NOL, all units were modified to reflect design changes (f) and (i) of Table 10. Item (i) was accomplished by removing the steel seal ring and replacing it with a Rulon "J" ring (Fig. 24). Item (f) required milling the surface of the rotor housing thrust face and inserting a steel washer around the rotor shaft to replace the removed material. A retest of all units was performed following modification. Results of the recalibration are given in Figure 28. A further shift downward in the arming speed was apparent from these tests. The disarm speed shifted downward slightly, but was almost the same as shown by the data in Figure 27.

49. Thirteen of the units were tested in accordance with reference (a), Figure 2 as shown in Figure 29 of this document. The high impact test was omitted, as the combined weight of the S&A and test fixture exceeded the capacity of the test machine. Units used in shock safety and jolt tests showed no degradation, except that the lugs on the units used in shock safety were cracked and broken. This was not considered a serious failure, as the test fixture was rigid while the actual mounting bracket will flex. The six units put through the environmental sequence were tested for arm/disarm points and detonator insulation resistance (results in Table 11). The high arming points occurring on two units were attributed to rust which formed on the steel thrust washer inserted around the rotor shaft (see par. 48). Unit 3075 armed normally after cleaning this washer. No anomalies were noted in the resistance checks.

50. Following the post-environmental calibration, the six units were again mounted in the test fixture and an attempt was made to fire the detonators. This test was not performed at low temperature or under high frequency vibration, as these requirements had proven impossible or impractical. Results of these firings are given in Table 12. Since reference (b) required a "... 3.0 ampere maximum ..." pulse, no effort was made to select a particular current, and initially a pulse of 0.050 second at approximately 2.3 amperes was used. Some of the detonators required several pulses to fire, while some did not fire at all. The current was then increased to about 2.7 amperes, which gave better results. However, some detonators still required multiple pulses. Finally, the current was increased to 2.9 amperes, at which point all detonators tested were fired on the first pulse. The tests at 2.9 amperes were performed on S&A's which had not been through environmental conditioning, although they had been used in some cold temperature studies. Based on the outcome of these firings, it was recommended that reference (b) be changed to read " ... a pulse of $3.0 \pm {}^{.5}_{0}$ amperes ...".

51. Four of the units mentioned above failed to disarm one or more times after firing. The rotor and nozzle assemblies of these units were disassembled and inspected after testing (results in Table 13). Three of these units were improperly assembled in that the Rulon "J" seal was installed upside down. Consequently, the seals were blown from the seal grooves in the rotor and broken into pieces which jammed between the rotor and housing. In the fourth unit, the Rulon "J" seal was installed properly, but was jammed with debris from the detonation. Much of the debris consisted of nickel plate from the rotor. Table 13 also includes data from nine units used in OPEVAL testing by VX-5, NWC, China Lake, California. Examination of these units revealed that more than half the rotors showed nickel plate flaking.

52. A total of 11 Phase IV S&A devices (including the nine mentioned in paragraph 51) was used in OPEVAL test firings. Forty-two rockets were fired with no mechanical or safety failures of the devices.

CONCLUSIONS

53. The Rocket Launcher Safety and Arming Device, MLU-53/B has been subjected to a thorough laboratory examination. In addition, it has been used in numerous rocket firings in field testing. The following conclusions are made:

a. The device as built and modified for the Phase IV testing cannot pass the required preproduction test sequence and function reliably.

b. By incorporating the modifications made by NOL on the Phase IV units into the design, changing the nickel plating on the rotor, and exercising greater quality control during manufacture, a device can be built which will operate according to specification.

c. In the disarmed state, the S&A protects the explosive initiating element from spurious electrical pulses and hazardous electromagnetic radiation (HERO). The initiating element is also held out-of-line with the explosive train so that accidental initiation will not cause motor ignition. The concept of a high speed turbine drive makes the S&A virtually impossible to arm until the required air speed (230 ± 20 knots) is reached. The energy expended to arm the device is stored in the actuator spring and then used to disarm the device when the minimum air speed (195 knots) is reached. These superior safety features of the MLU-53/B represent a quantum step toward a safer weapon system.

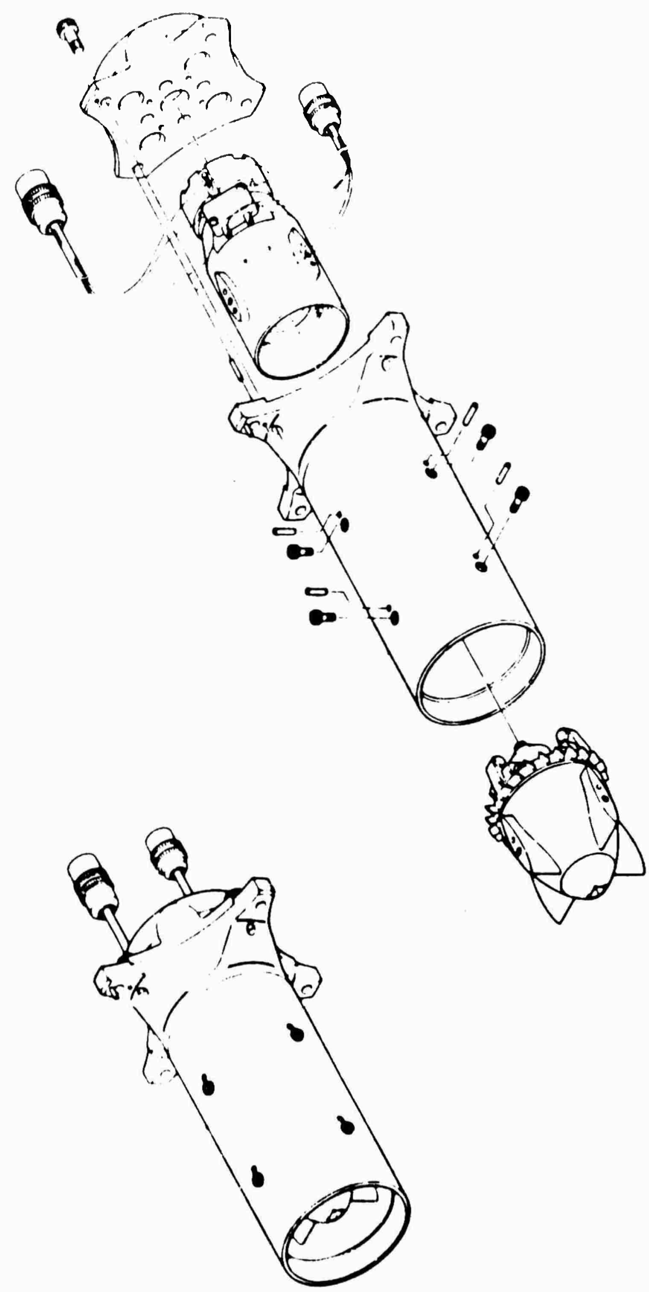


FIG. 1 PHASE I SAFETY AND ARMING DEVICE ASSEMBLY BREAKDOWN

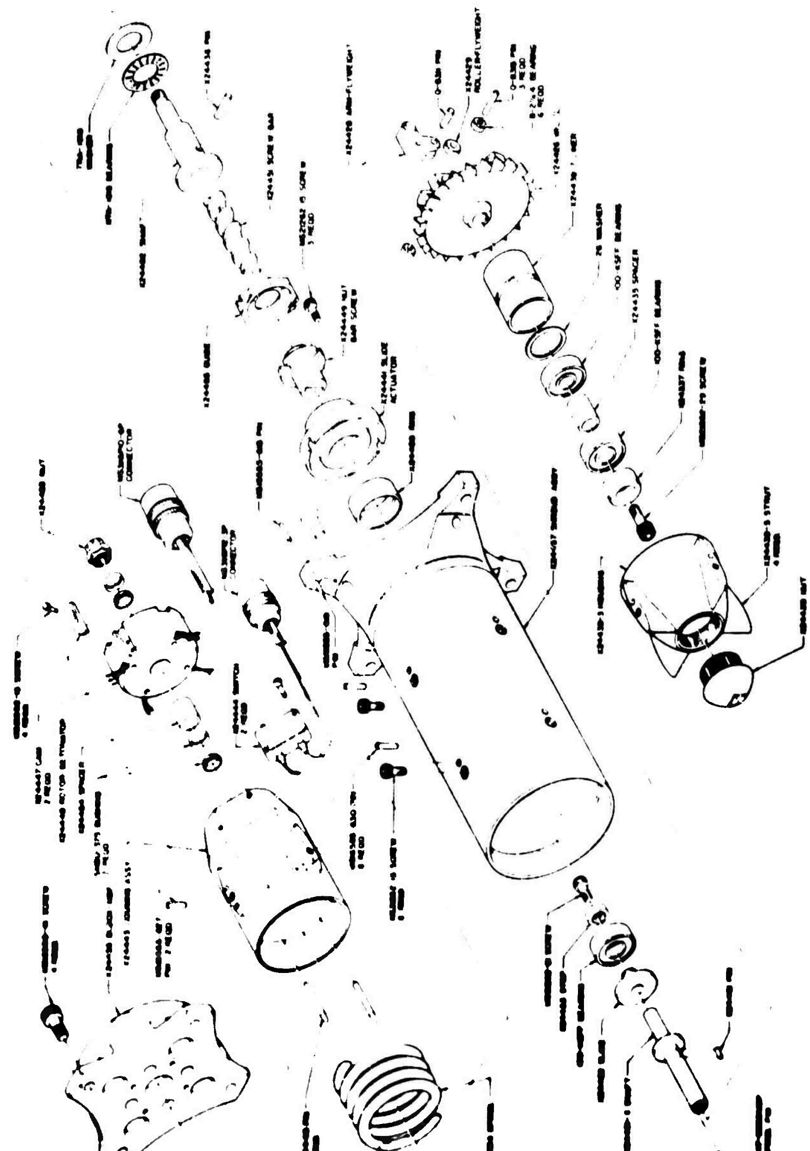


FIG. 2 PHASE I SAFETY AND ARMING DEVICE EXPLODED VIEW

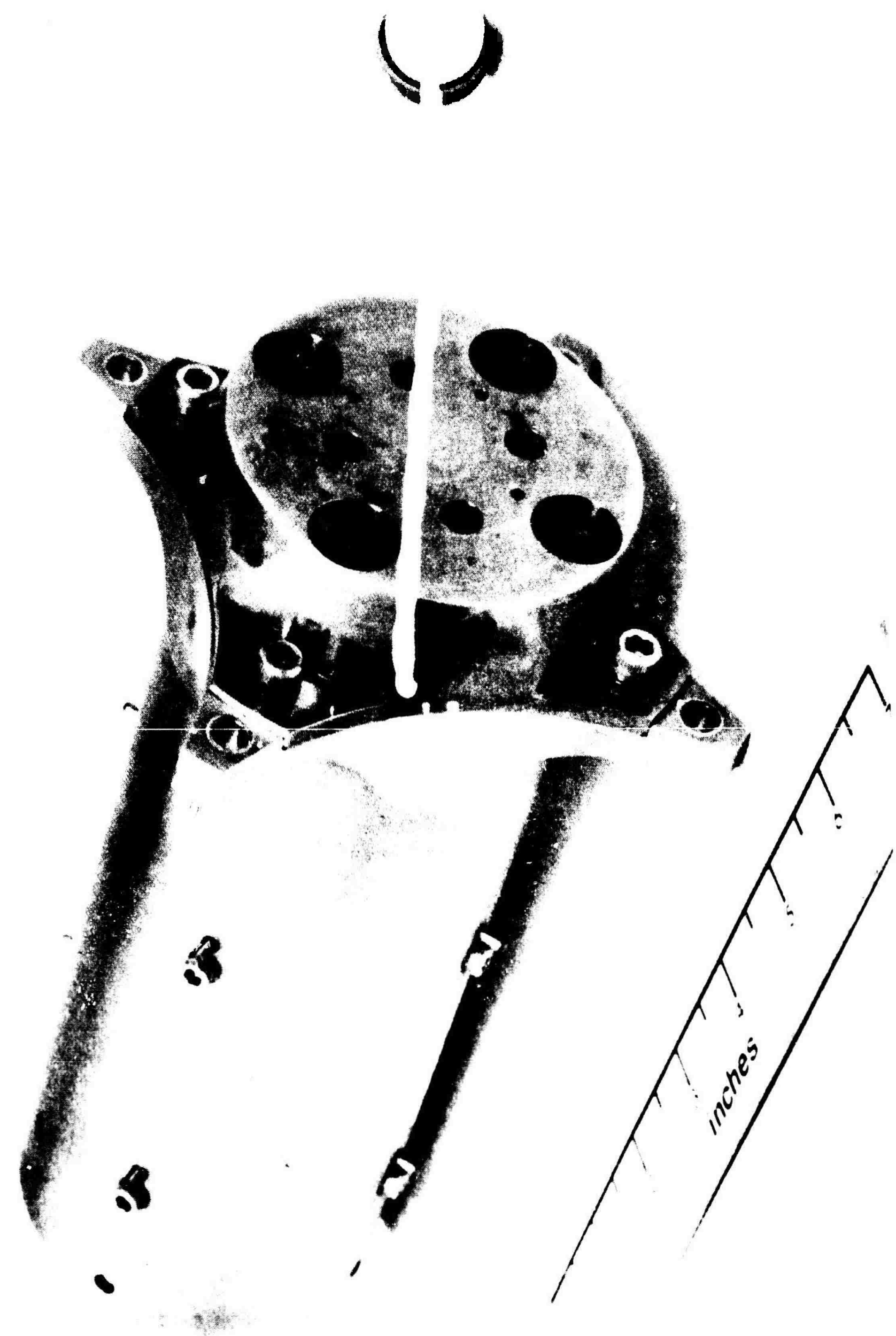


FIG. 3 PHASE I SAFETY AND ARMING DEVICE

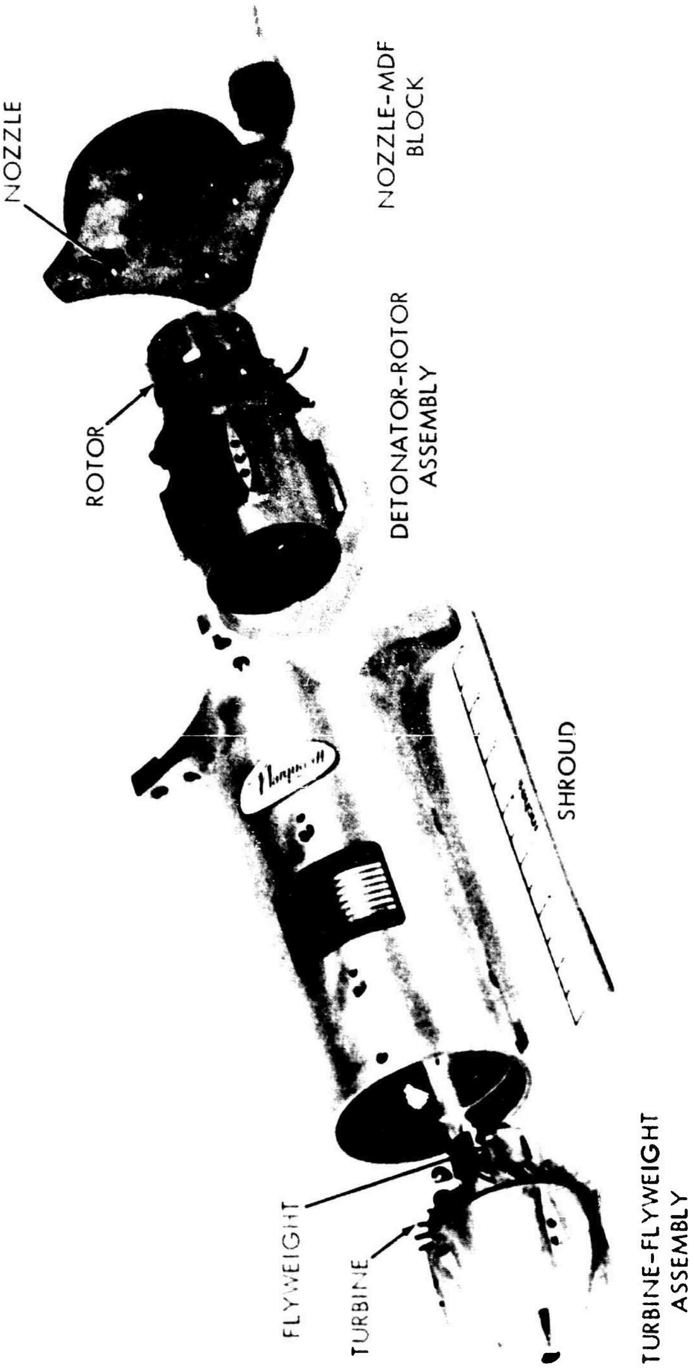


FIG. 4 PHASE I SAFETY AND ARMING DEVICE EXPLODED VIEW

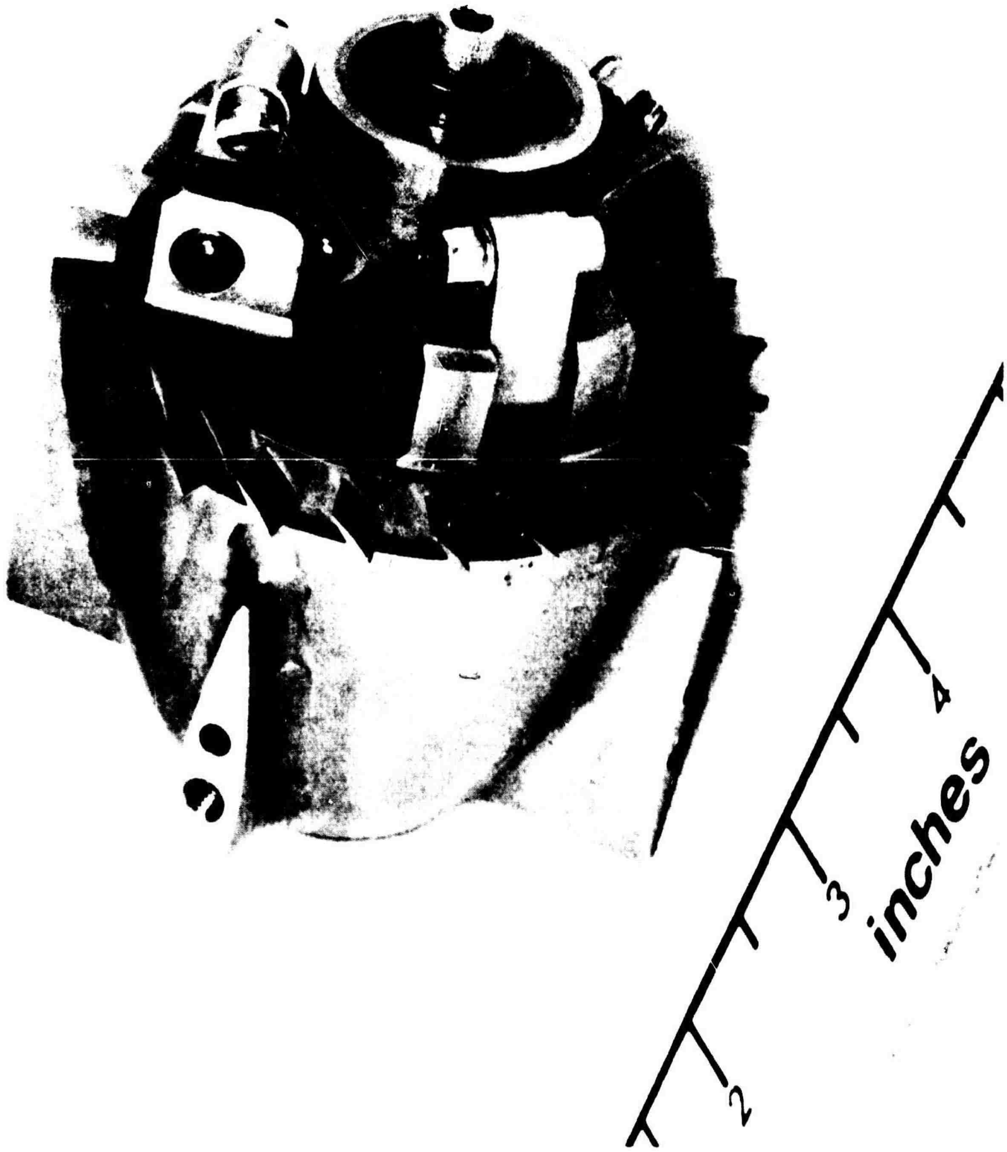


FIG. 5 PHASE I SAFETY AND ARMING DEVICE TURBINE WHEEL BALANCE ASSEMBLY

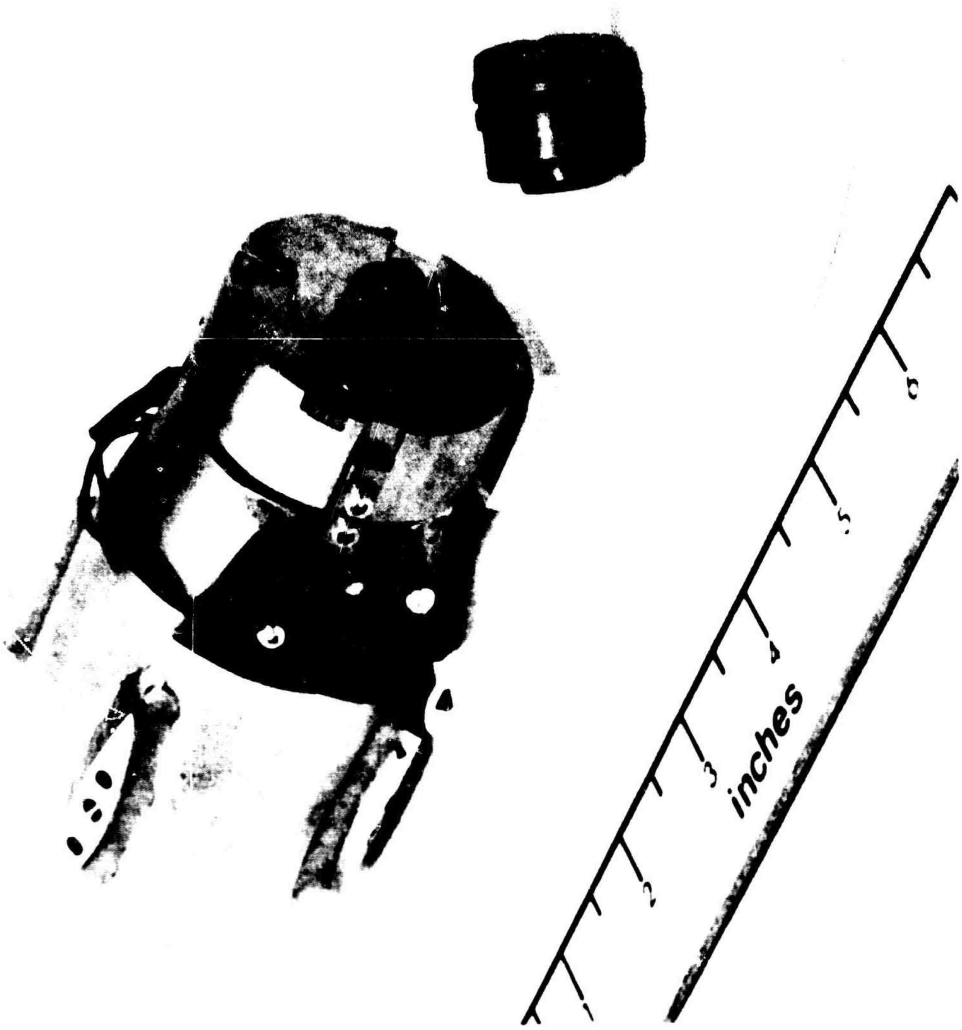


FIG. 6 PHASE I SAFETY AND ARMING DEVICE ROTOR AND ACTUATOR ASSEMBLY

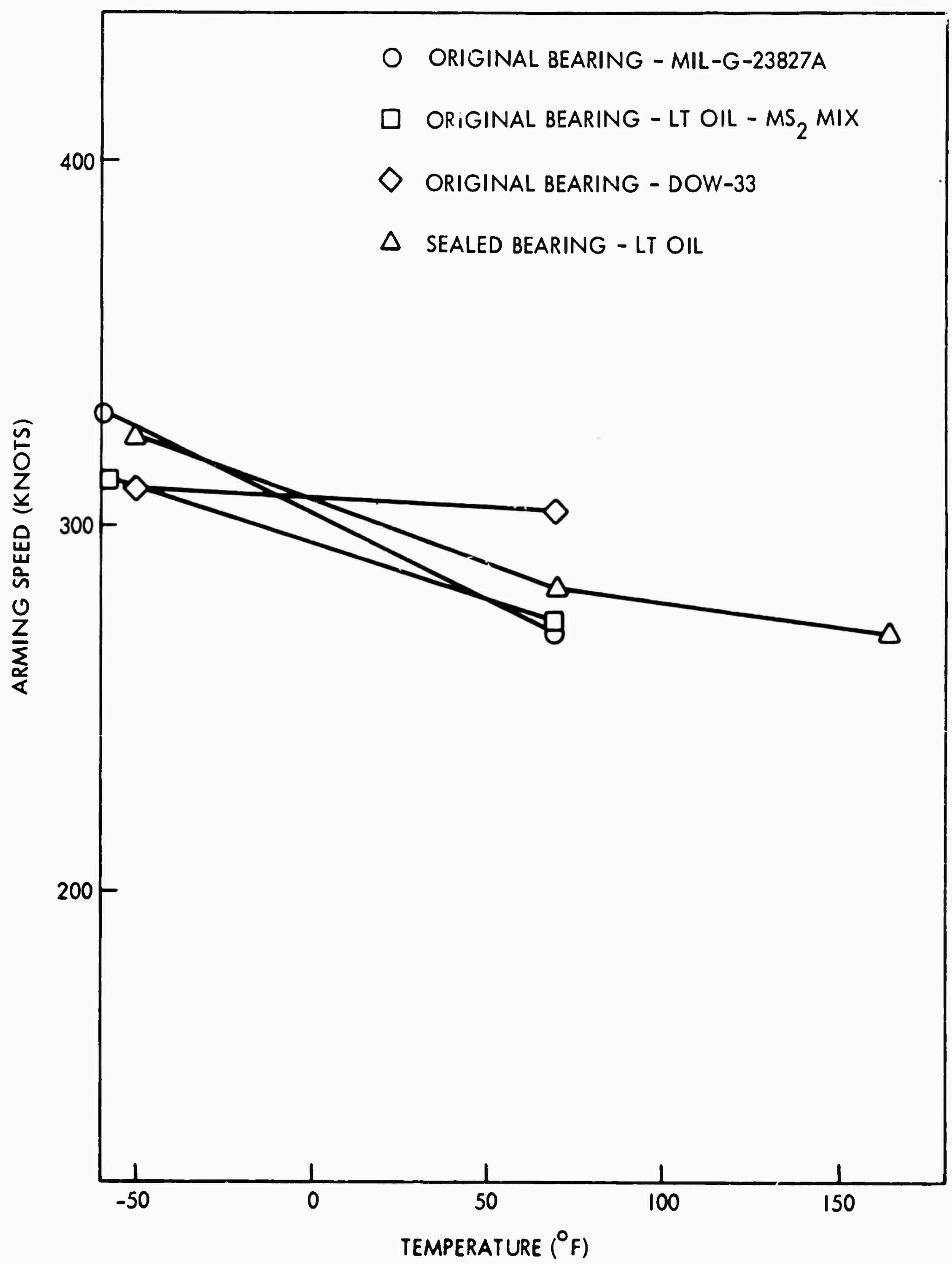


FIG. 7 EFFECT OF TEMPERATURE ON ARMING POINT OF PHASE I S&A

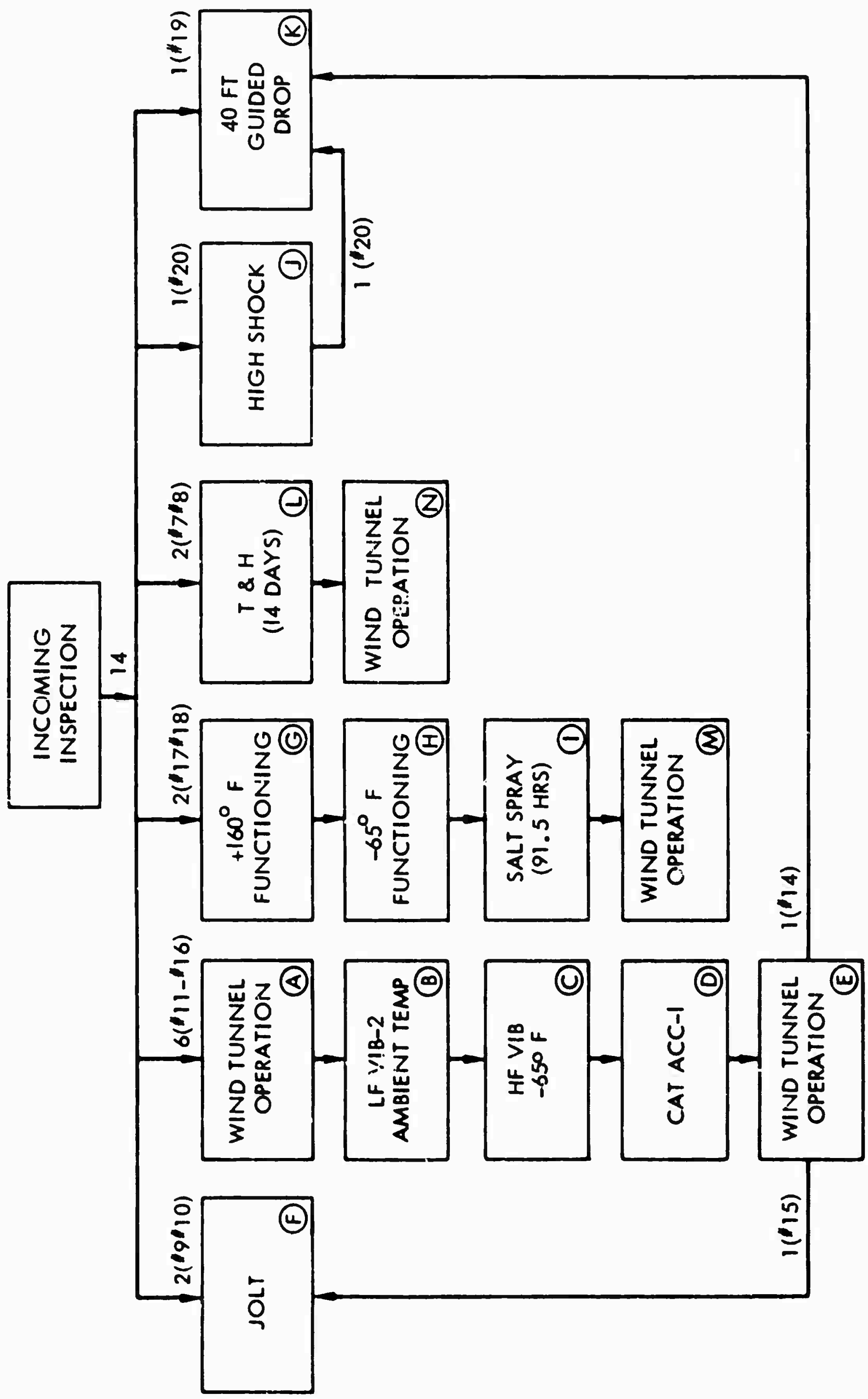


FIG. 8 PHASE I S&A DEVICE TEST FLOW CHART

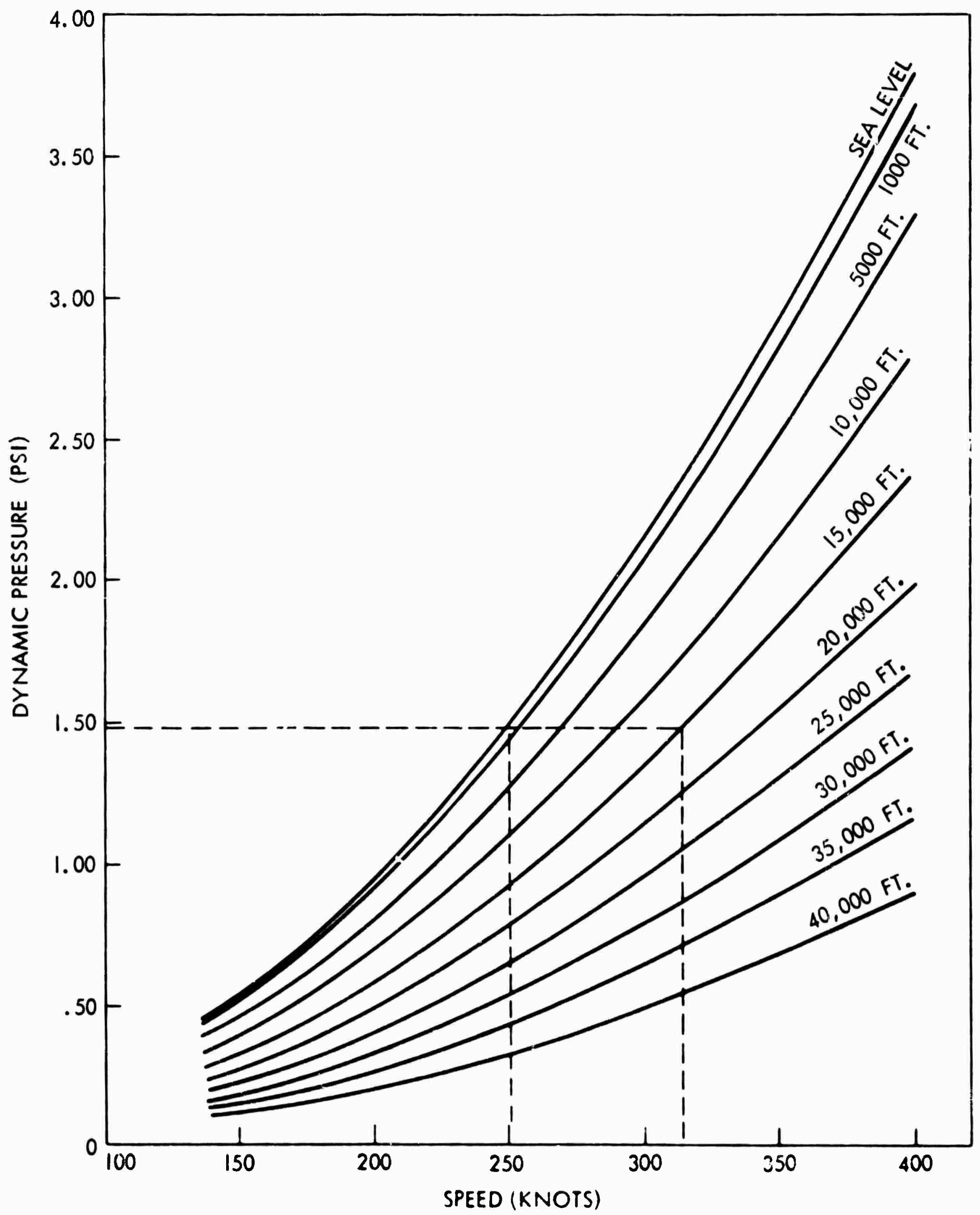


FIG. 9 EFFECT OF SPEED AND ALTITUDE ON DYNAMIC PRESSURE

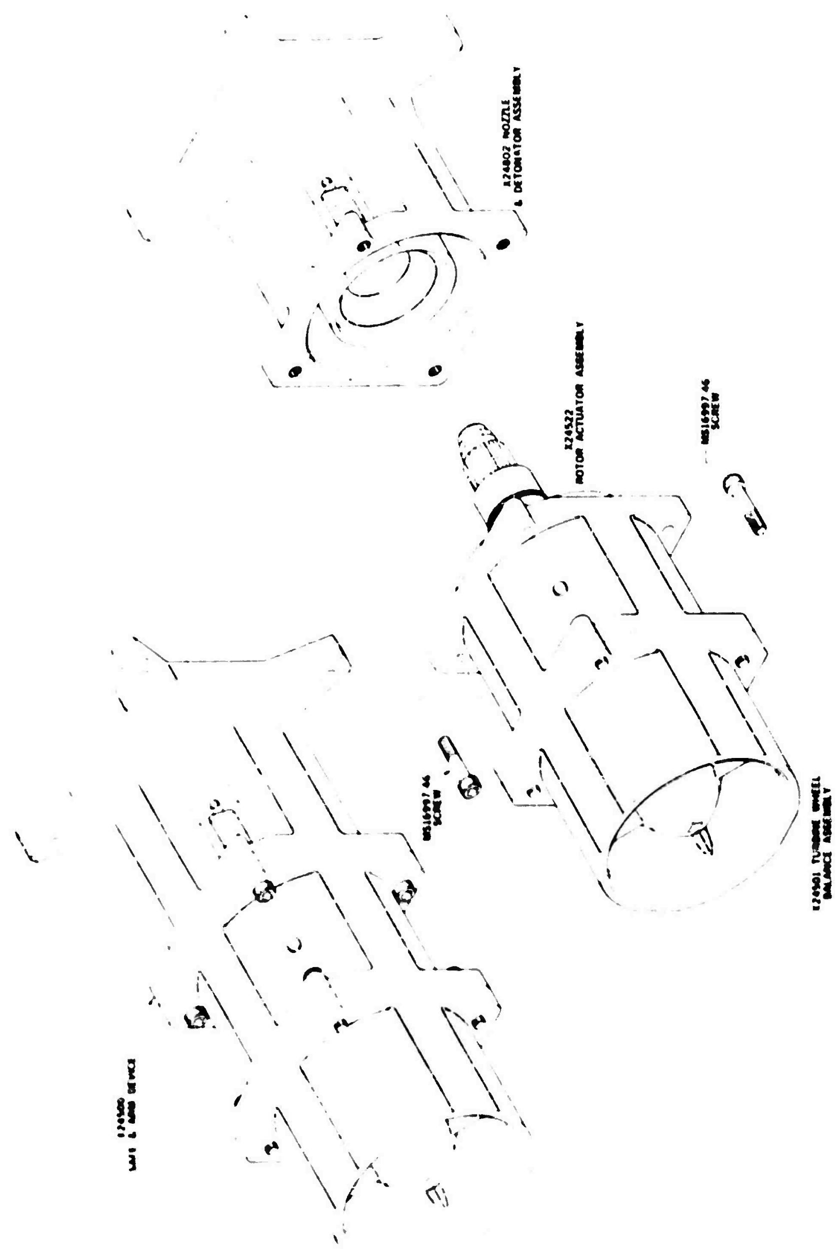


FIG. 10 PHASE II SAFETY & ARMING DEVICE

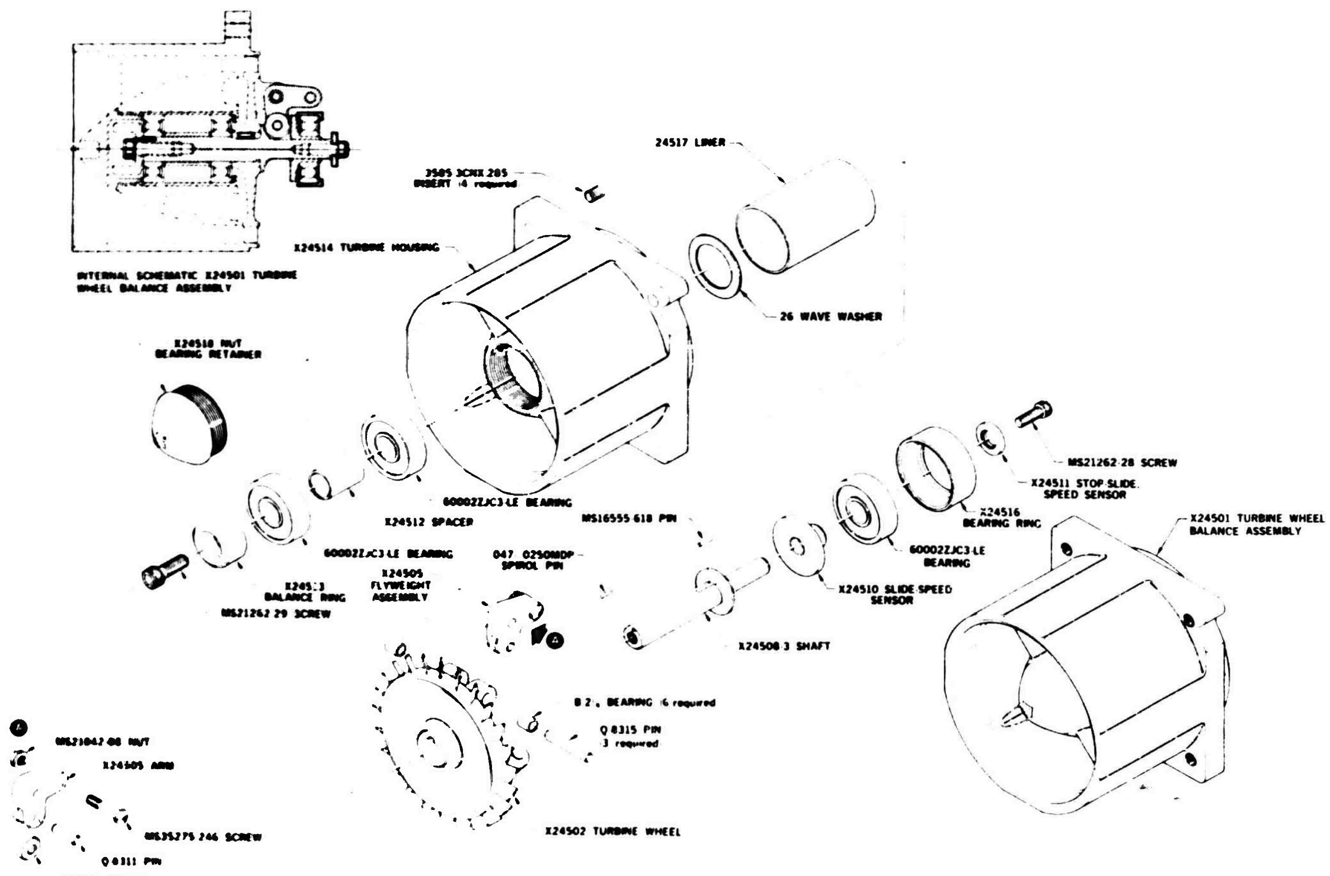


FIG. 11 PHASE II TURBINE WHEEL BALANCE ASSEMBLY

FIG. 12 PHASE II ROTOR ACTUATOR ASSEMBLY

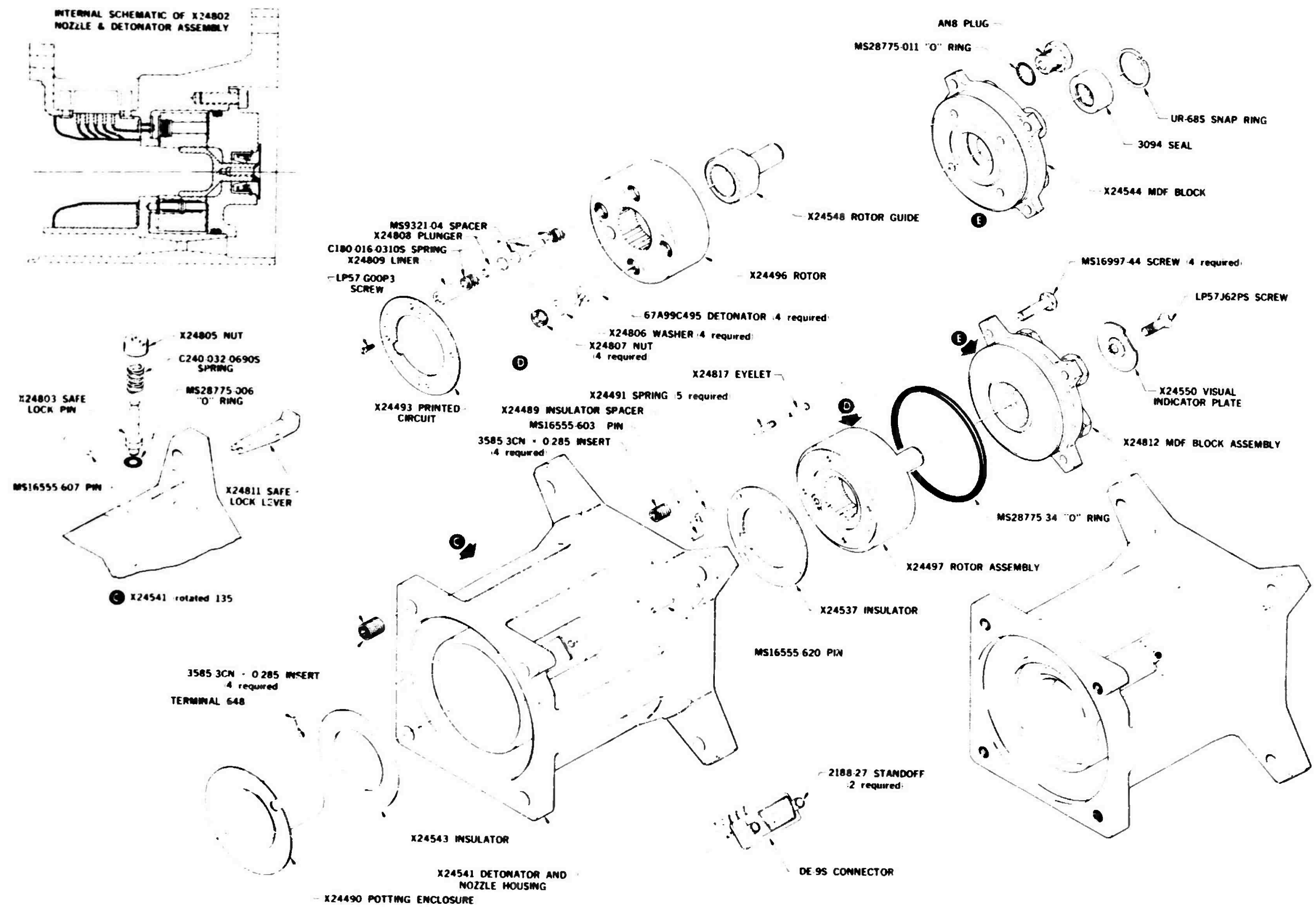


FIG. 13 PHASE II DETONATOR & NOZZLE ASSEMBLY & MDF BLOCK

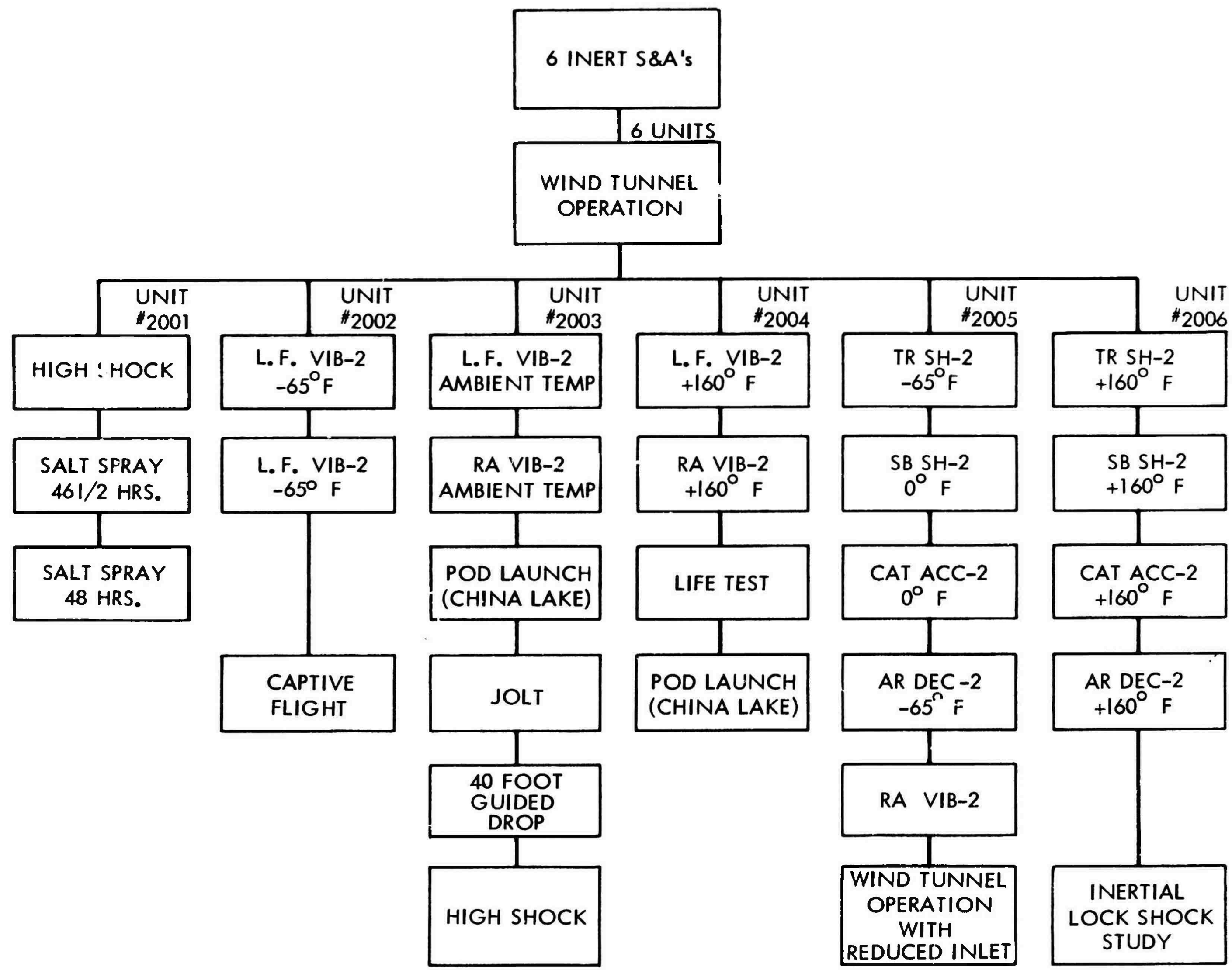


FIG. 14 PHASE II S&A DEVICE TEST FLOW CHART

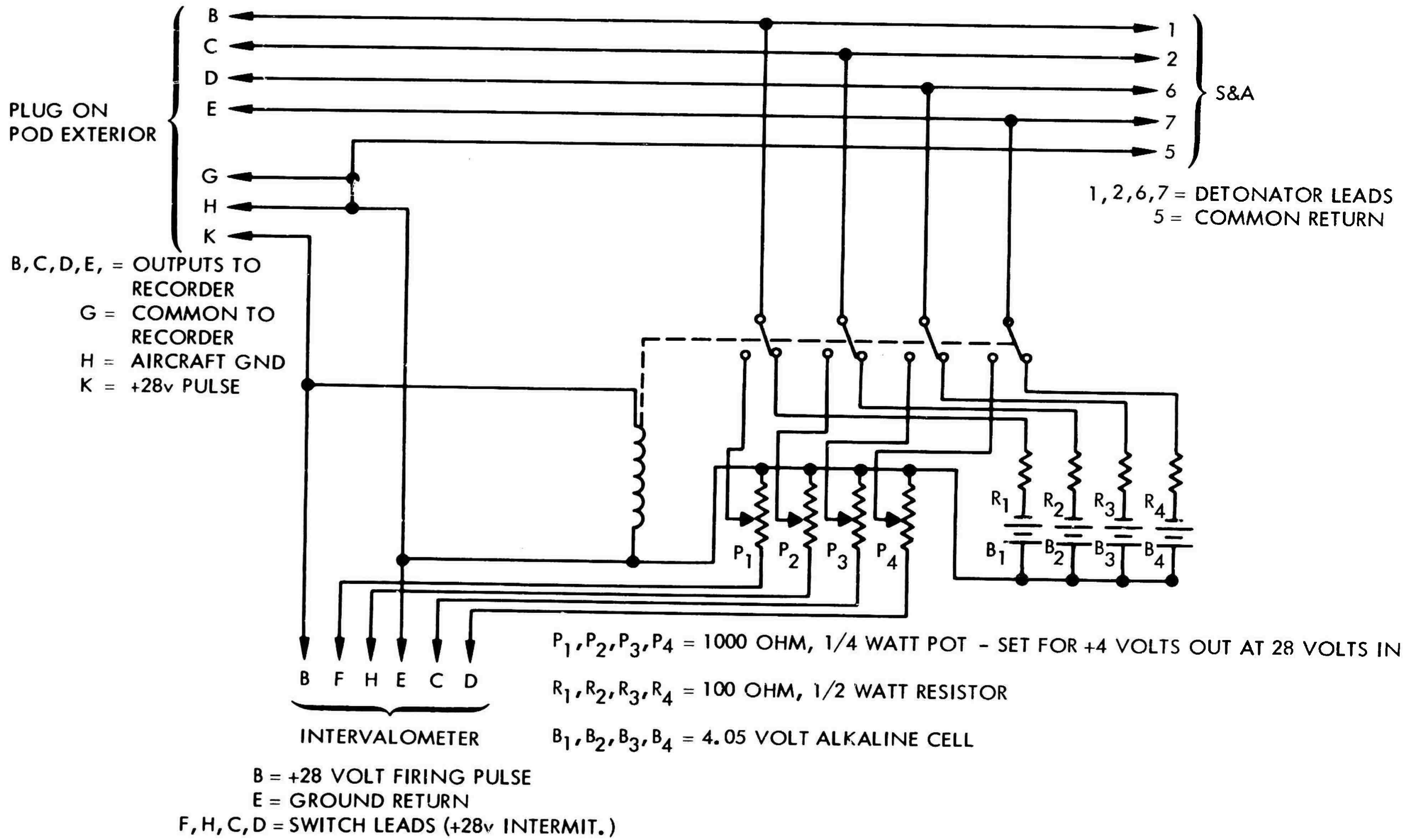


FIG. 15 "FLY-AROUND" POD WIRING CIRCUIT FOR THE PHASE II S&A

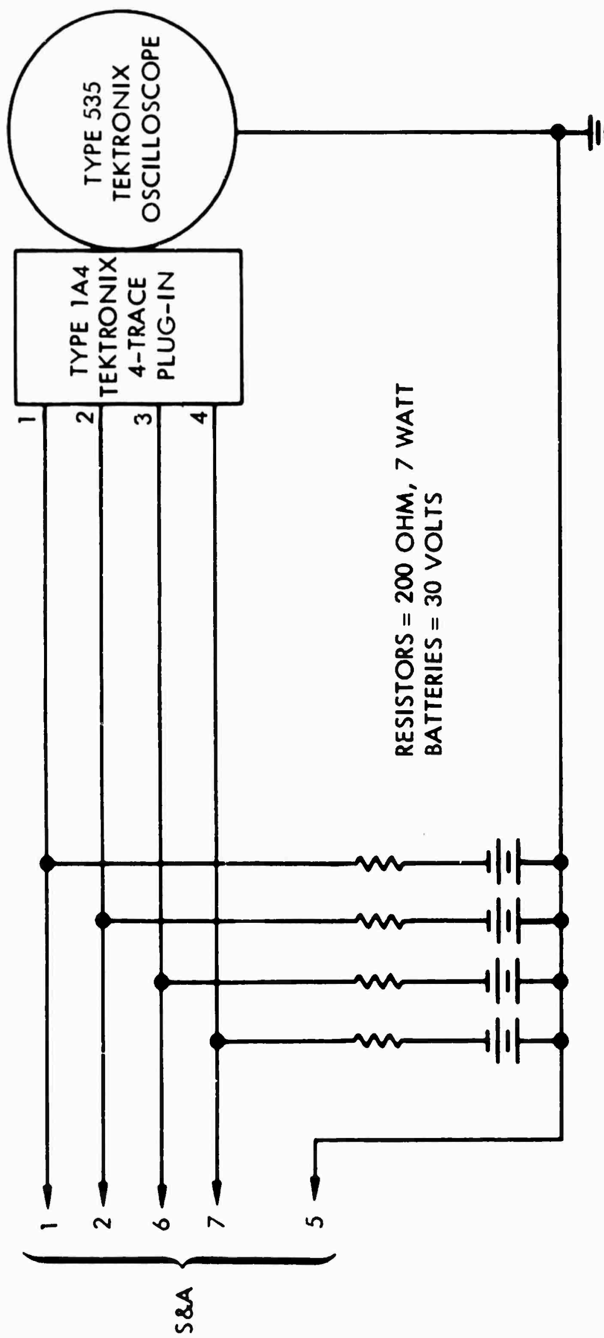


FIG. 16 S&A SWITCH MONITOR CURRENT

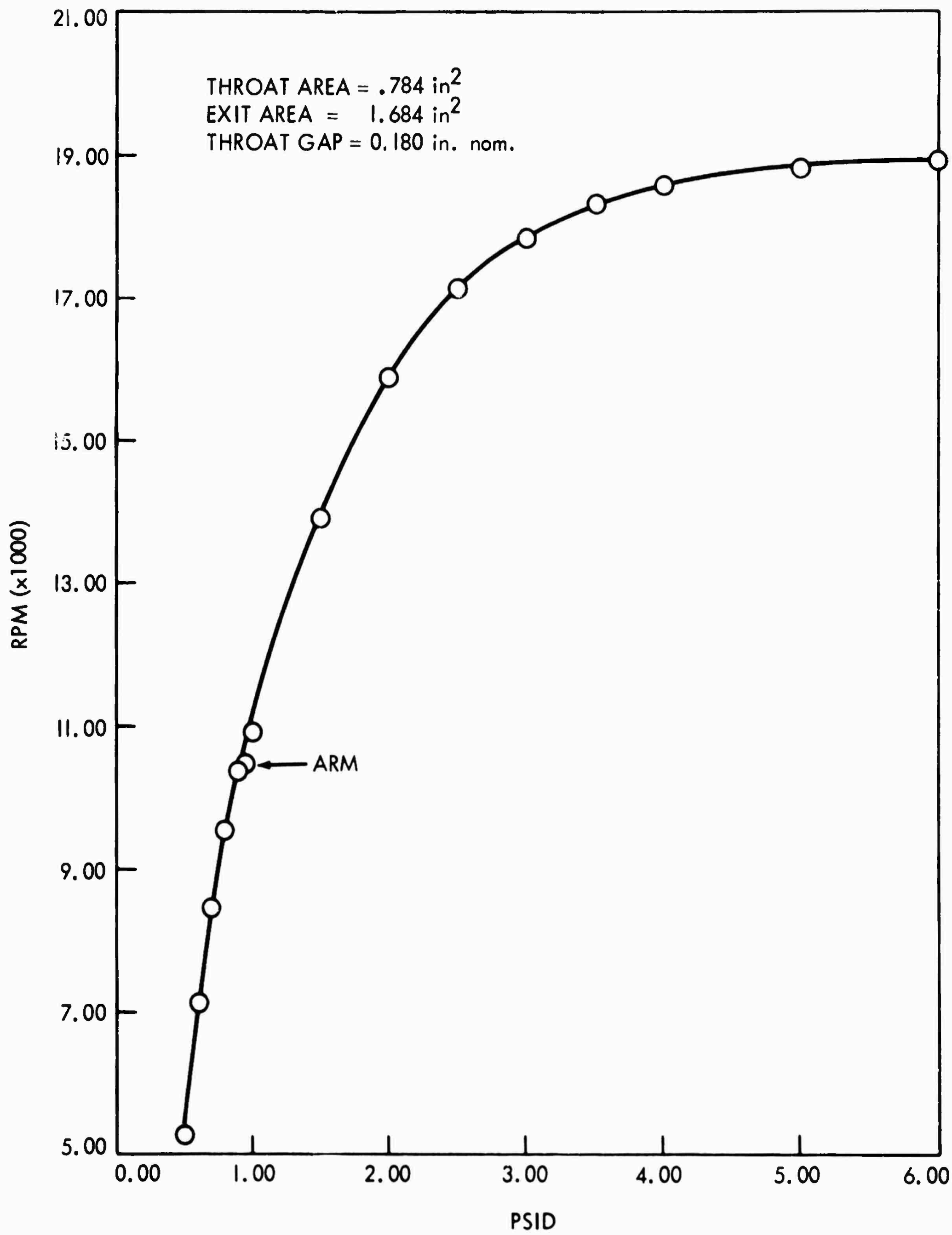


FIG. 17 S&A DEVICE TU-3
TURBINE SPEED VS PRESSURE DIFFERENTIAL

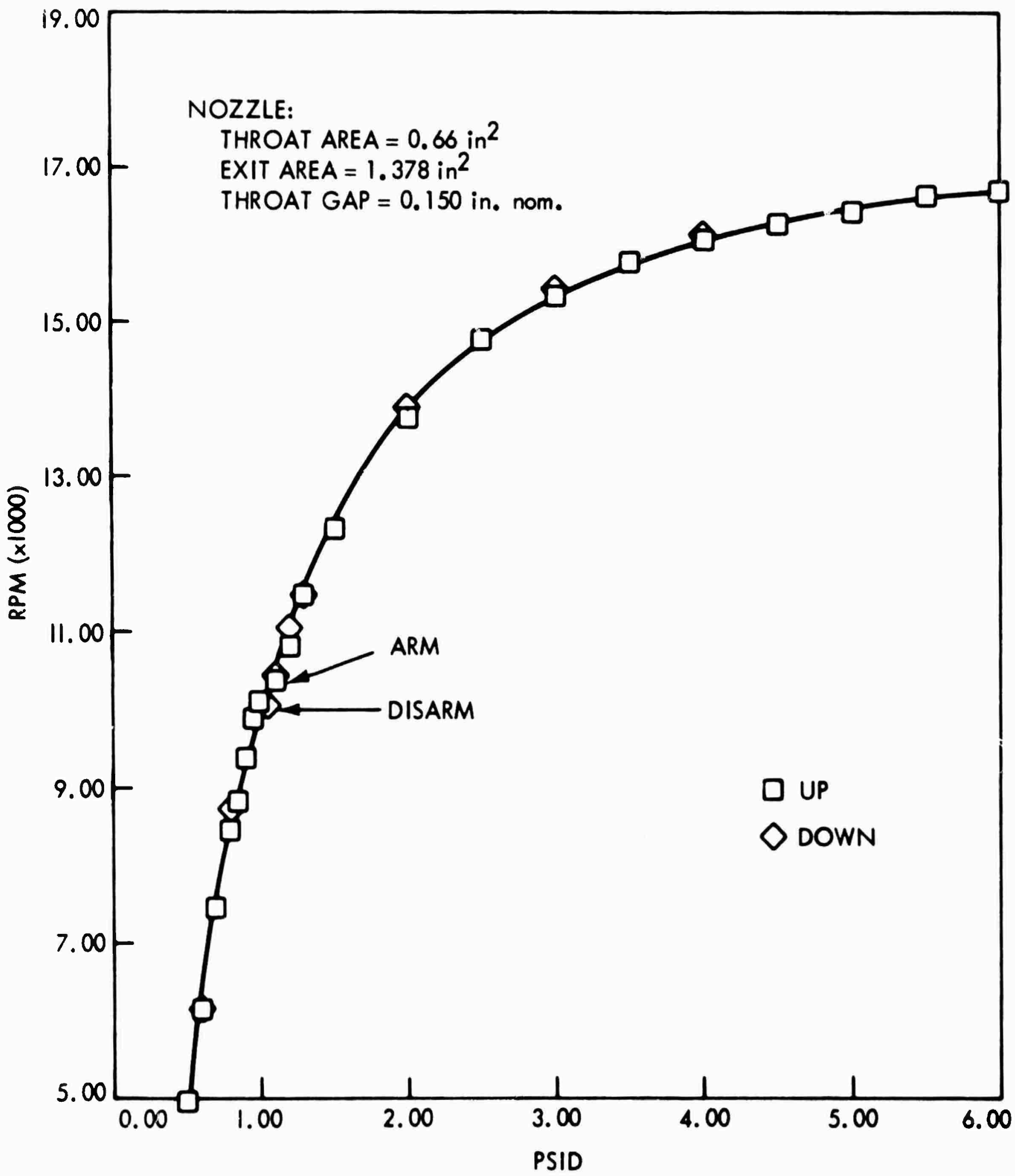


FIG. 18 S&A DEVICE TU-3
TURBINE SPEED VS PRESSURE DIFFERENTIAL
DIE CAST NOZZLE TEST

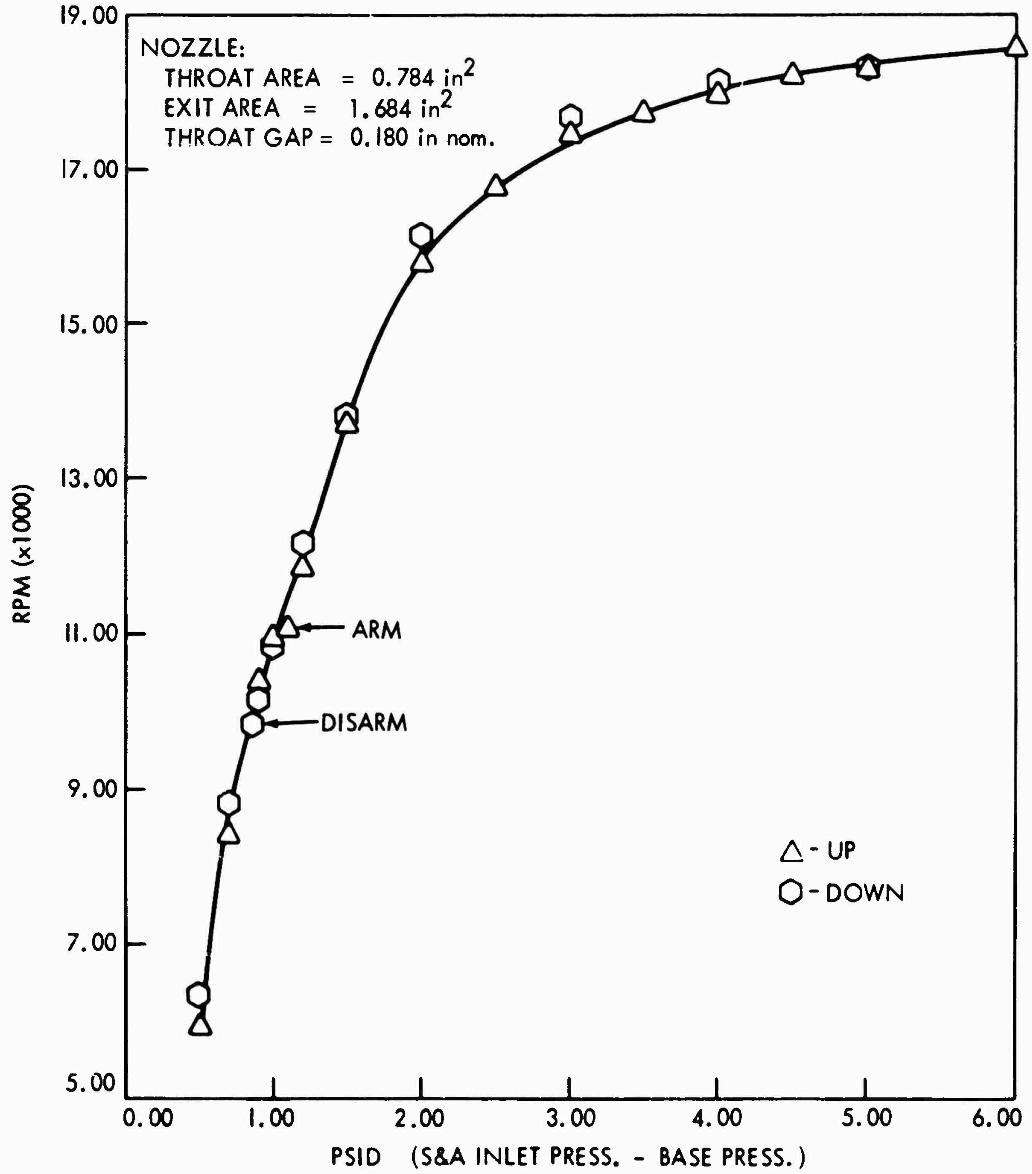


FIG. 19 S&A DEVICE TU-4
TURBINE SPEED VS PRESSURE DIFFERENTIAL

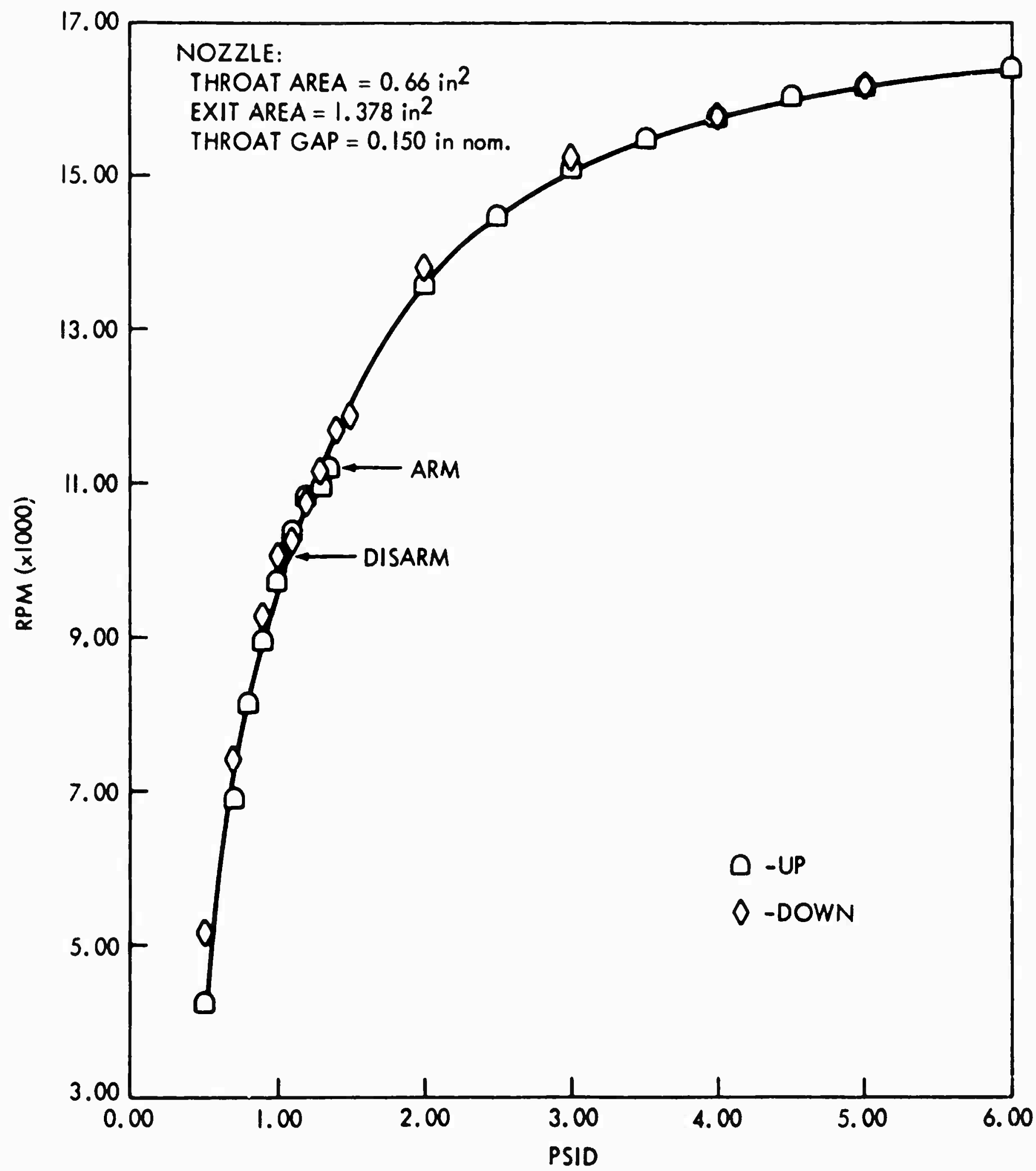


FIG. 20 S&A DEVICE TU-4
DIE CAST NOZZLE TEST

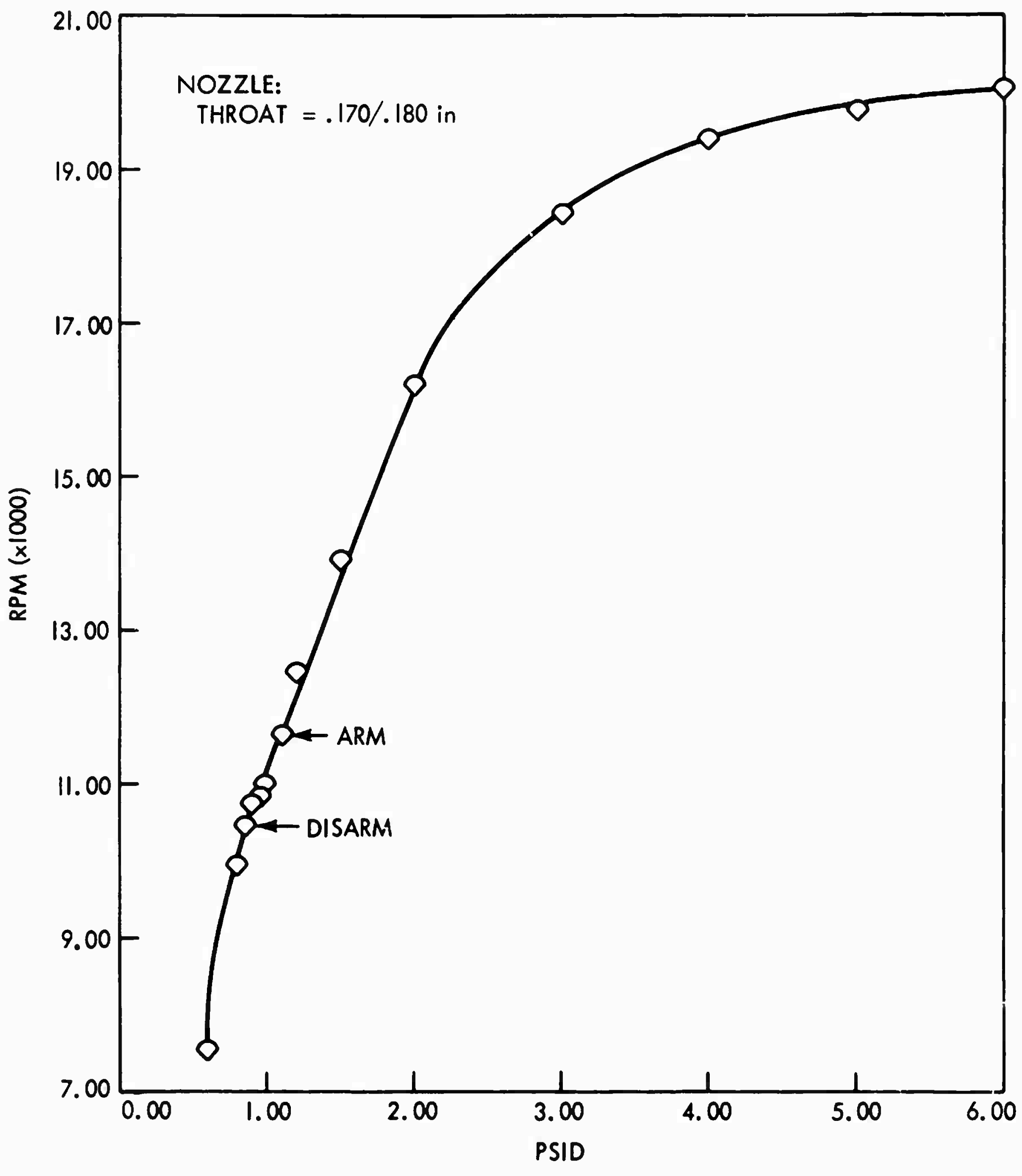


FIG. 21 DIE-CAST NOZZLE TEST

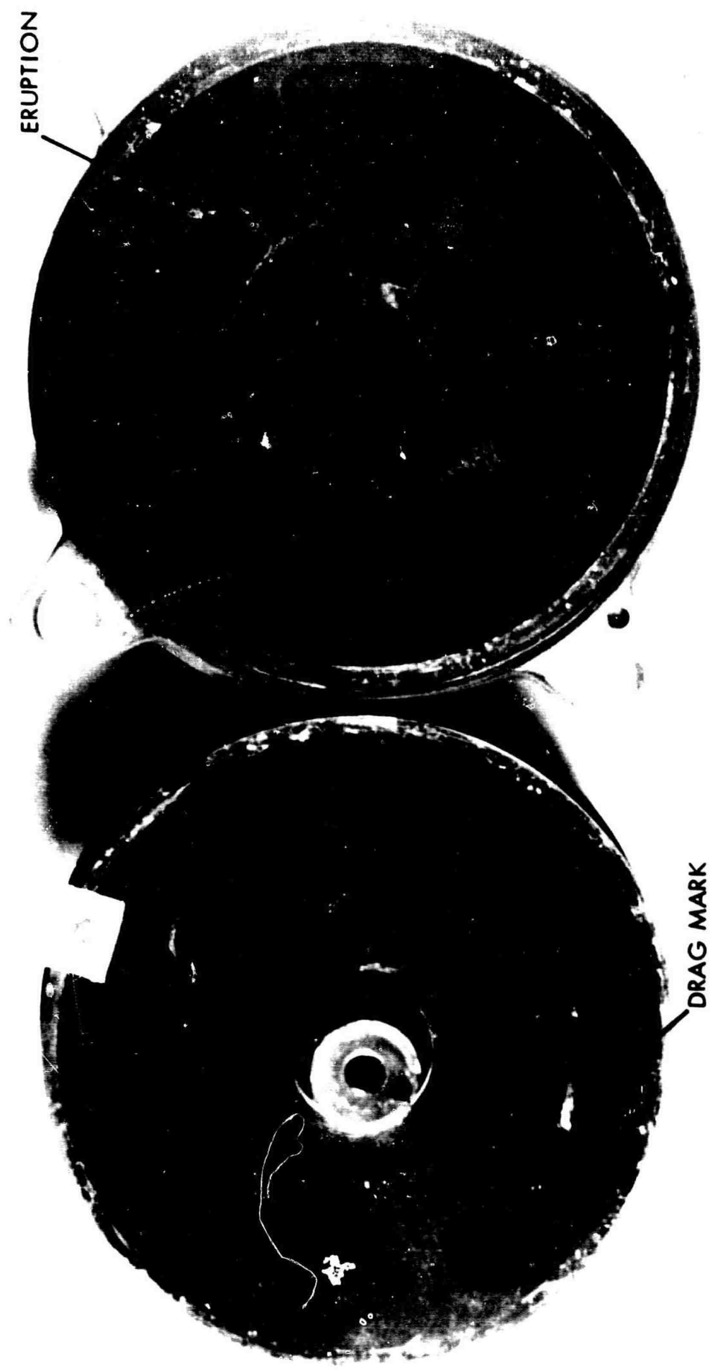


FIG. 22 VIEW OF ROTOR AND MDF BLOCK SHOWING BLOCK ERUPTION AND ROTOR DRAG MARK

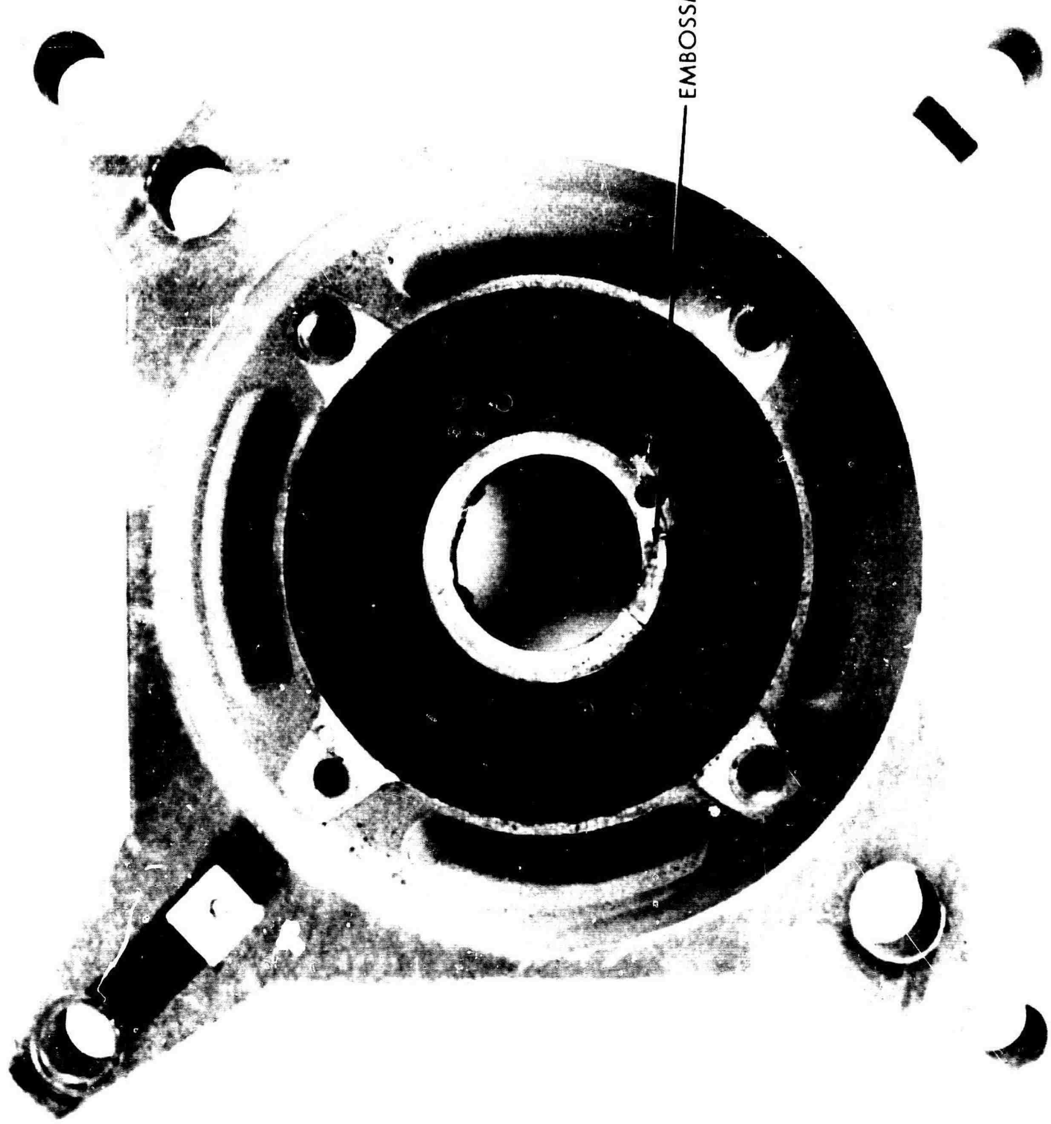
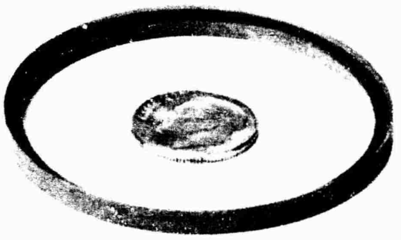


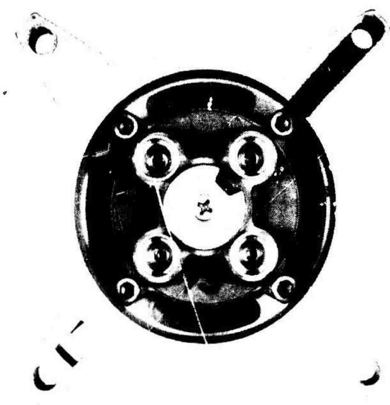
FIG. 23 VIEW OF ROTOR CAVITY SHOWING EMBOSSMENT OF THRUST FACE



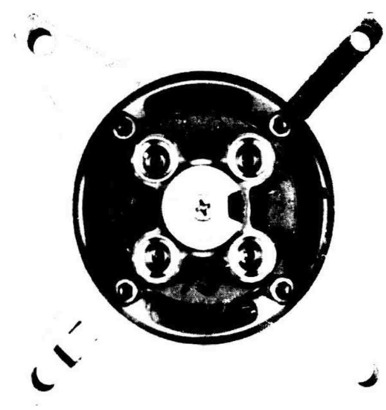
(a)

(b) CROSS-SECTION

FIG. 24 RULON "J" SEAL RING



(a) "SAFE" POSITION



(b) "ARMED" POSITION

FIG. 25 S&A MODE INDICATOR

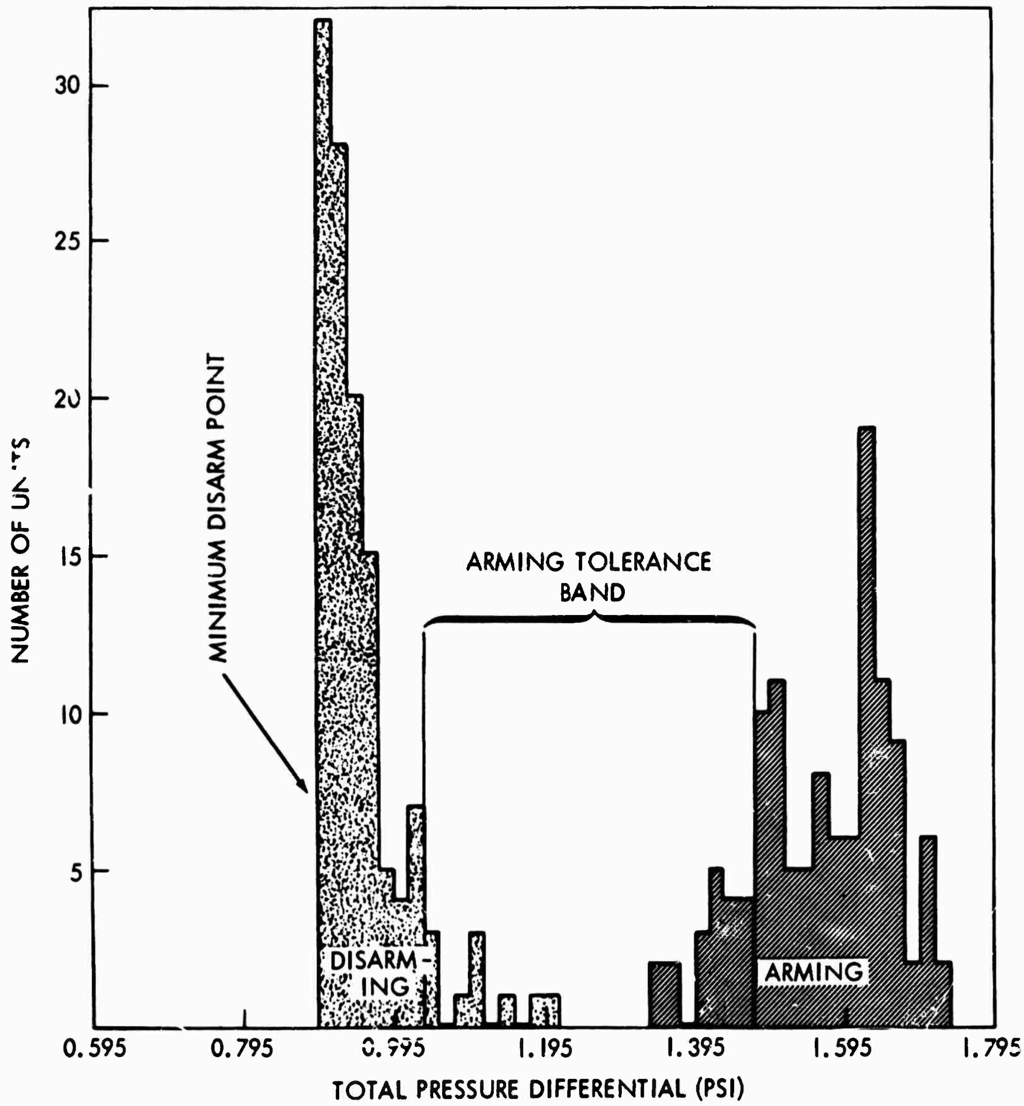


FIG. 26 PHASE IV ARM/DISARM POINTS AS DETERMINED BY TMC

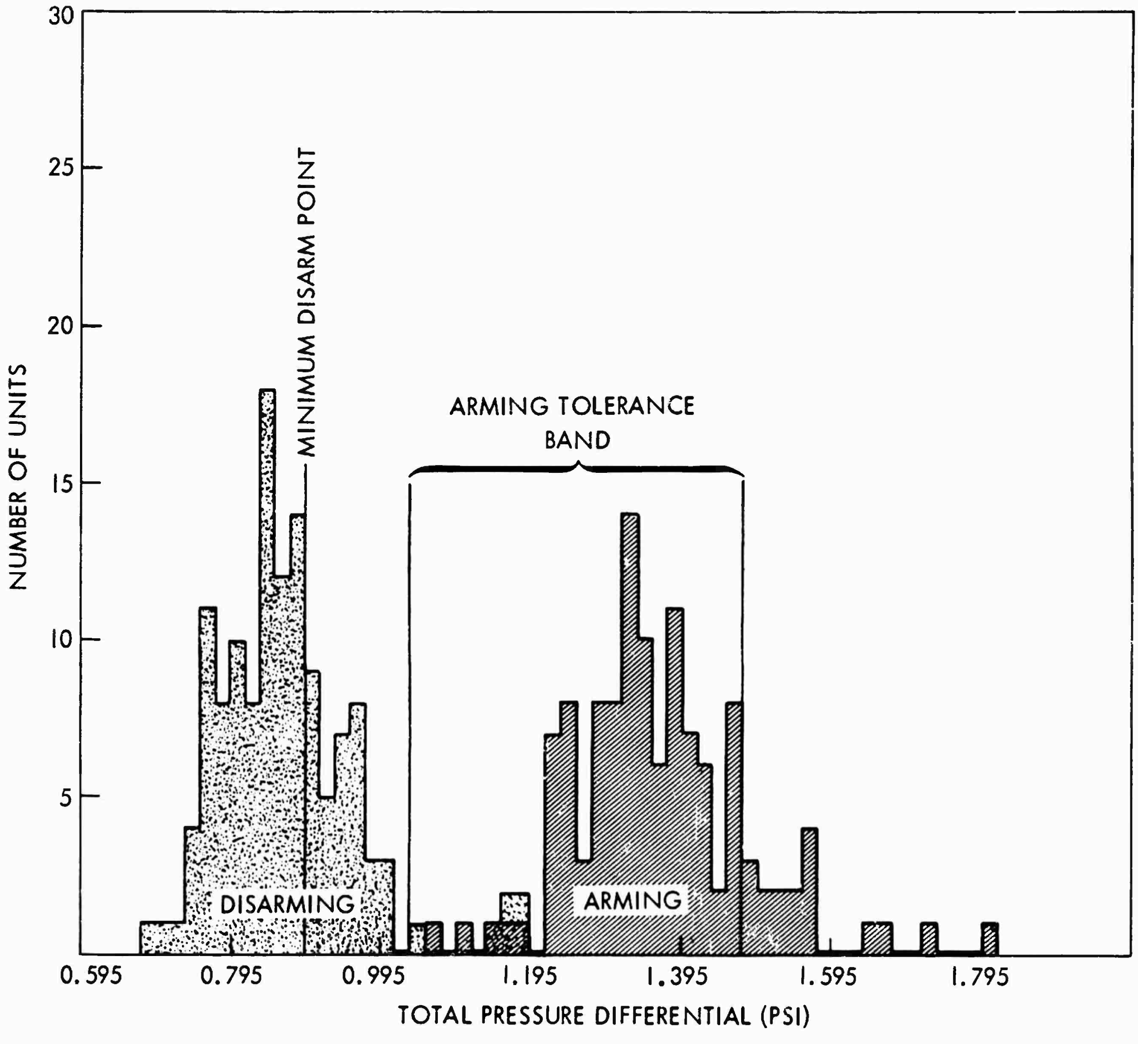


FIG. 27 PHASE IV ARM/DISARM POINTS AS RECEIVED AT NOL

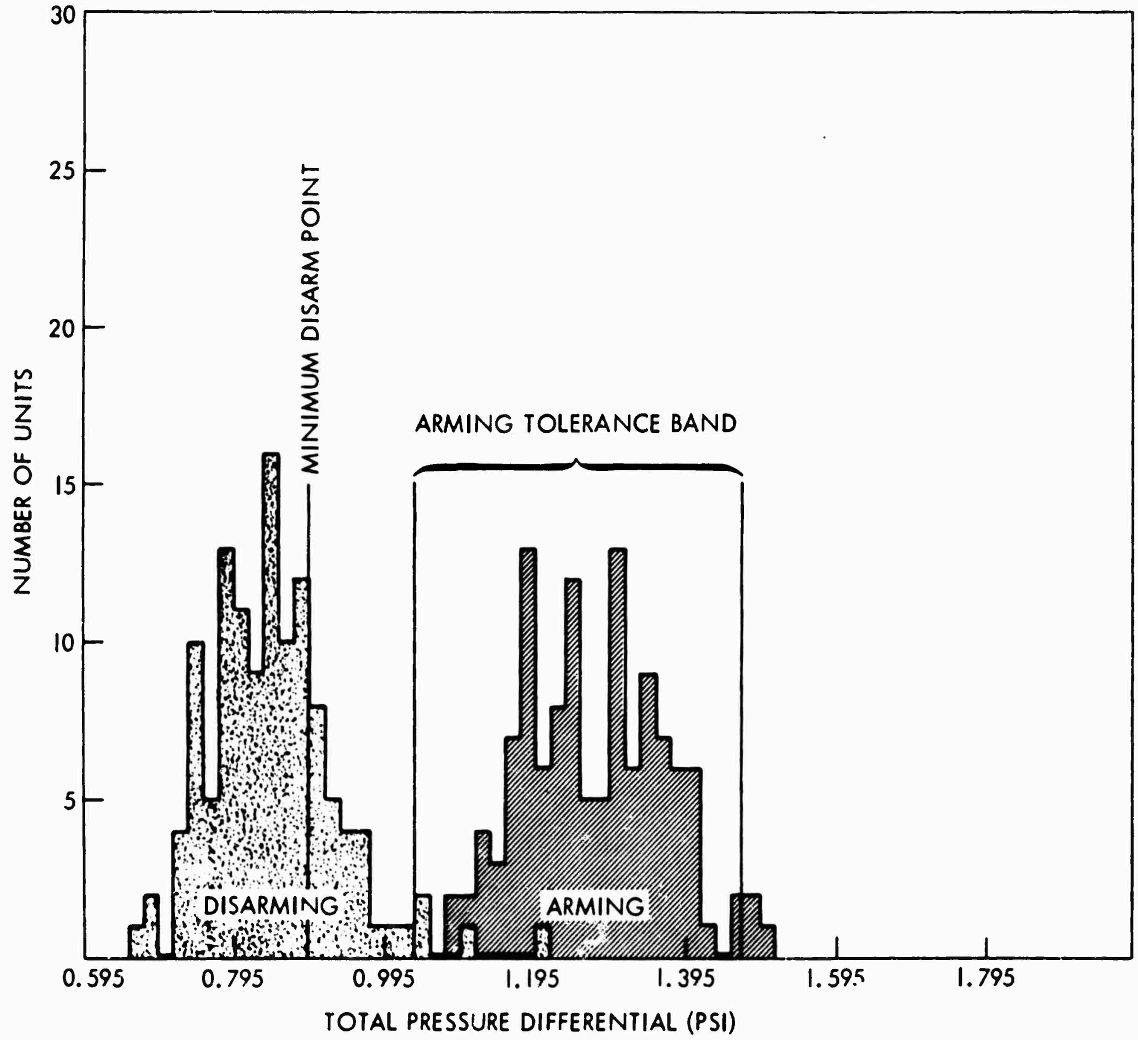


FIG. 28 PHASE IV ARM/DISARM POINTS AFTER MODIFICATION AT NOL

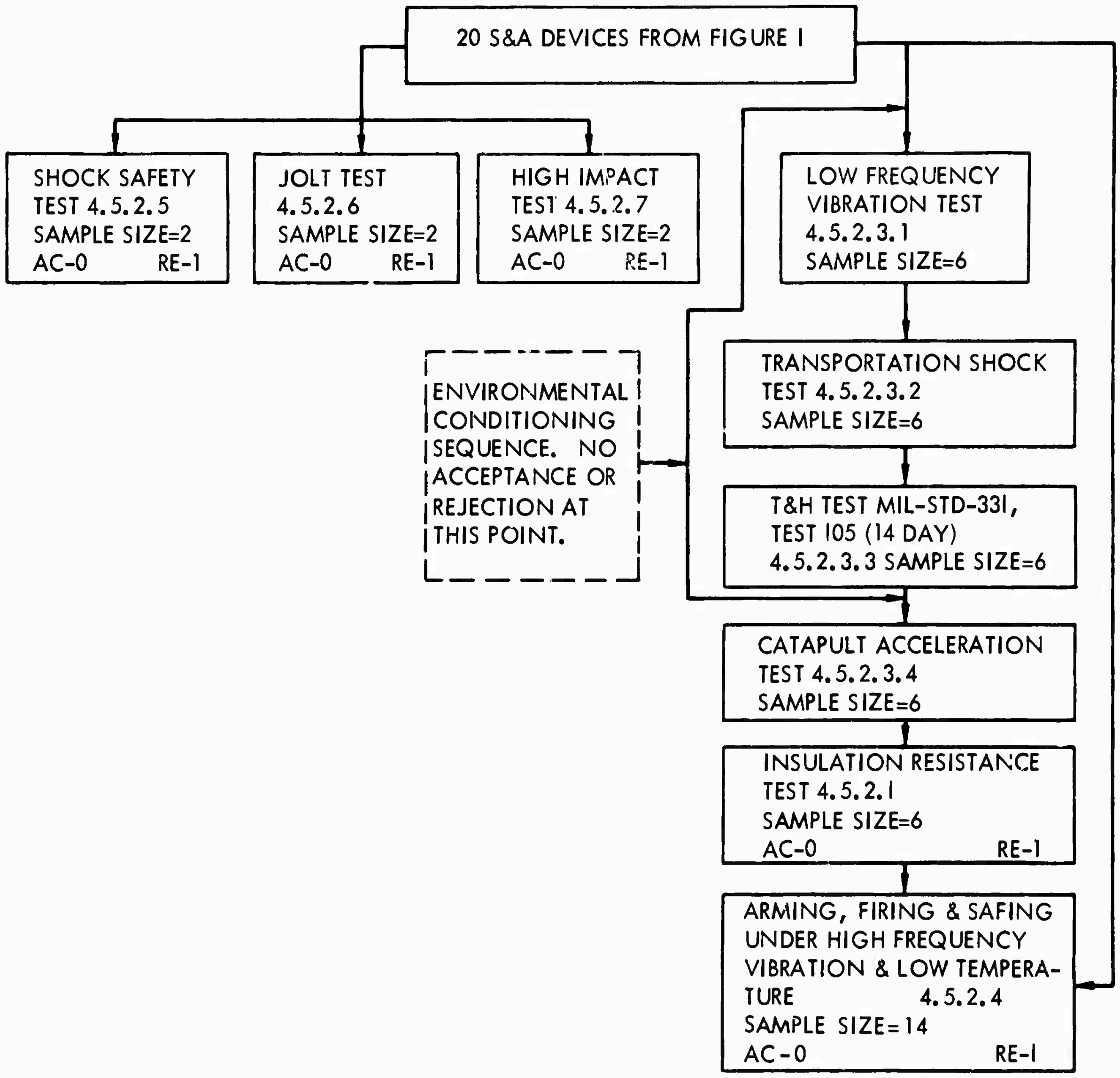


FIG. 29 PREPRODUCTION TESTS FOR S&A DEVICE TO BE CONDUCTED AT TEST ACTIVITY DESIGNATED BY PROCURING AGENCY

Table 1

RESULTS FROM DEVELOPMENT TESTS TO OBTAIN THE DESIRED S&A CALIBRATION

Condition	Arm Speed, Knots	Arm ΔP, psi	Disarm Speed, Knots	Disarm ΔP, psi
1. Results from initial assembly	315	2.40	275	1.80
2. Same as 1 with heavier flyweights	295	2.05	265	1.67
3. Same as 2 with nozzle exit diameter increased from 0.60" to 0.66"	270	1.73	243	1.40
4. Same as 2 with nozzle exit diameter increased from 0.60" to 0.69"	250	1.48	225	1.20

Table 2

ARM AND DISARM CONDITION FOR THE 20 LOT I S&A DEVICES DELIVERED TO NOL

S/N	Arm ΔP, psi	Disarm P, psi
0001	1.66	1.42
0002	1.66	1.31
0003	1.68	1.40
0004	1.62	1.49
0005	1.74	1.30
0006	1.61	1.37
0007	1.70	1.28
0008	1.92	1.49
0009	1.73	1.27
0010	1.80	1.30
0011	1.62	1.35
0012	1.44	1.10
0013	1.73	1.52
0014	1.74	1.48
0015	2.00	1.60
0016	1.60	1.30
0017	1.93	1.50
0018	1.90	1.64
0019	1.74	1.58
0020	1.81	1.35

Table 3

PHASE I S&A DEVICE TEST SUMMARY

Test	Serial No.	Type of Test	Result
A	#11-#16	Wind Tunnel Operational	Average arming speed 320 knots, disarmed speed 280 knots.
B	#11-#16	Low Frequency Vibration	No failure was observed; connector pins A and B were monitored, no switch closure.
C	#11-#16	High Frequency Vibration (-65°F)	#14 rotor moved 13° and 3 mounting screws were loose; no switch closure was observed.
D	#11-#16	Catapult Shock	No additional movement was observed on #14 rotor.
E	#11-#16	Wind Tunnel Operational	Not much deviation from A above.
F	#9 #10 #15	Jolt	No failure was observed; connector pins A and B were monitored, no switch closure.
G	#17 #18	+160°F (4 hrs) Functioning	Dark grease came out, presumably from bearings.
H	#17 #18	-65°F (4 hrs) Functioning	Average arming speed 444 knots, disarmed at 323 knots.
I	#17 #18	Salt Spary	Rust appeared on MDF blocks; bearings contaminated after 91.5 hours of testing.
J	#20	Shock Safe 1,500g	Unit armed; rotor moved 90° and jammed.
K	#14 #19 #20	40-Ft Guided Drop	All micro switches were broken; no other failure was observed.
L	#7 #8	Temp & Humidity (28 days)	Rust appeared on MDF blocks.
M	#17 #18	Wind Tunnel Operational	Average arming speed 366 knots, disarmed at 305 knots.
N	#7 #8	Wind Tunnel Operational	Average arming speed 344 knots, disarmed at 236 knots.

Table 4

LIST OF OPEN ENGINEERING DEVELOPMENT ITEMS AFTER COMPLETION OF PHASE II

Affected Area	Problem	Action Required
Detonator Housing and Rotor Cavity Configuration	A. Rotary Switch cavity axial length not critical.	A. Tolerance relief possible on printed circuit board and insulators.
	B. Interference of safe lock pin with rotor.	B. Investigation of the amount of rotation possible when an 0.008 axial gap exists between rotor shaft and actuator housing.
	C. Possible interference between rotor assembly and detonator housing in the vicinity of the inertial lock.	C. Relocation or a different method required of staking the inertial lock liner to the rotor.
Rotor and Actuator Positioning and Mounting Configuration	Possible interference between mating splines at final assembly.	Spline internal clearance must be analyzed via inspection of parts and a ten times size layout for the comparator. Also maximum torque required to prevent rotation of the male spline must be investigated.
Detonator Rotor Configuration	Prevention of P.C. boards failure from detonator firing effects.	Reroute the detonator leads to the P.C. board. Isolate the debris from the printed circuit area. Epoxy the P.C. board to the rotor and also increase the P.C. board thickness.
Turbine Balance Assembly	A. Maintaining the .149-.151 slider travel.	A. Check squareness of the turbine wheel shaft end with respect to its axis. Also check squareness of the slider stop.
	B. Elimination of cracking of turbine wheel hub during heat treat.	B. Change material from 431 stainless to 17-4 PH.

Table 4

LIST OF OPEN ENGINEERING DEVELOPMENT ITEMS AFTER COMPLETION OF PHASE II (Cont'd)

Rotor Actuator Assembly	A.	Difficulty in assembling actuator slide to mating location pin - blind assembly.	A.	Radius the slot and match mark the slide at the forward end.
	B.	Guide Assembly becomes egg shaped when the retaining bolts are torqued.	B.	Lower bolt torque.
	C.	Slide actuator retaining pins difficult to assemble.	C.	Increase size of drilled holes in actuator housing.
	D.	Axial deformation of the bar screw during assembly.	D.	Review and evaluate assembly techniques. Modify as required.
	E.	Possible interference between spring O.D. and actuator housing.	E.	Check the amount of spring unwind when it undergoes compression to working height.
Miscellaneous	A.	Interference of electrical harness with S&A housing.	A.	Relocate the slot on the opposite side.
	B.	Interference of S&A mounting flange with ZAP launcher.	B.	Evaluate and locate interference. Modify the aft mounting flange finishing dimensions.
	C.	Visual indicator plate interference.	C.	Increase the rotor guide overall length.

Table 5

ARM/DISARM PRESSURE DIFFERENTIALS WITH CORRELATED AIR SPEED FOR PHASE II S&A'S

	Arm		Disarm	
S/N	Δ P, psi	Air Speed, Knots	Δ P, psi	Air Speed, Knots
2001	1.24	267	0.75	218
2002	1.18	261	0.76	219
2003	1.23	266	0.88	231
2004	1.23	266	0.74	217
2005	1.16	259	0.74	217
2006	1.18	261	0.84	227

Table 6

SYNOPSIS OF PHASE II S&A TEST RESULTS

Unit No.		Operable After Test?	Comment
2001	High Shock	Yes	Shocked three times - inertial lock held.
2001	Salt Spray - 46½ hrs	Yes	Minor salt deposits.
2001	Salt Spray - 48 hrs	Yes	More salt deposits (total 94½ hrs).
2002	LFVIB-2 (-65°F)	Yes	Operation at -65°F was sluggish.
2002	RAVIB-2 (-65°F)	Yes	Unit could not be operated on vib. table due to lack of sufficient air.
2002	Captive Flight	Yes	Test circuit shown in Figure 16. Results listed in Table 7.
2003	LFVIB-2 (RT)	Yes	
2003	RAVIB-2 (RT)	Yes	Switch chatter indicated.
2003	Pod Launch	Yes	Unit was blown from pod and ingested dirt when it struck the ground. It operated after cleaning dirt out.
2003	Jolt	Yes	
2003	40-Foot Guided Drop	Yes	MDF block dislodged on basedown drop. Bearings sounded rough after tests.
2003	High Shock	No	Would not operate after the shock.
2004	LFVIB-2 (+160°F)	Yes	
2004	RAVIB-2 (+160°F)	Yes	Switch chatter indicated.
2004	Life Test	Yes	Ran total of 40 hrs with no degradation apparent.
2004	Pod Launch	Yes	Proved out N_2 arming system.
2005	TRSH-2 (-65°F)	Yes	
2005	SBSH-2 (0°F)	Yes	

Table 6

SYNOPSIS OF PHASE II S&A TEST RESULTS (Cont'd)

Unit No.	Test	Operable After Test?	Comment
2005	CATACC-2 (0°F)	Yes	Temperature could not be maintained due to test length.
2005	ARDEC-2 (-65°F)	Yes	Temperature could not be maintained due to test length.
2005	RAVIB-2	Yes	Switch chatter caused by foreign material on solder covered contacts.
2005	Wind Tunnel Test with reduced inlet	Yes	Minimum inlet diameter to allow unaffected operation is about 1.75 to 2.0 inches.
2006	TRSH-2 (+160°F)	Yes	
2006	SBSH-2 (+160°F)	Yes	
2006	CATACC-2 (+160°F)	Yes	Temperature could not be maintained due to test length.
2006	ARDEC-2 (+160°F)	Yes	Temperature could not be maintained due to test length.
2006	Inertial Lock Shock Study	Yes	Bar screw failure revealed during this test - all units refitted with new bar screws. The inertial lock was found to be adequate.

Table 7

SUMMARY OF PHASE II S&A CAPTIVE FLIGHT TEST RESULTS
(Unit Number 2002)

Arm/Disarm Altitude (Feet)	Arm/Disarm Indicated Velocity (Knots)	Remarks
820/600 5380/5300 25,000/no record 30,000/30,000	247/235 271/241 304/no record 327/251	Forward fairing broken after first arm point - 2½" ID tube from forward bulkhead of pod to the S&A.
800/990 4770/5200 15,330/14,680 24,000/24,620	263/216 273/253* 293/245 351/293	Forward fairing broken after first arm point - 2½" ID tube restricted with a 2" opening on forward bulkhead.

*Data point suspect.

Table 8

MANUFACTURER'S ARM/DISARM TEST DATA, PHASE III S&A

S/N	Using Phase II Noz. Assy, Nozzle Area = .81 in² Arm ΔP, PSI	Arm Knots	Disarm ΔP, PSI	Disarm Knots	Phase III Nominal Noz. Area = .66 in² Arm ΔP, PSI	Arm Knots	Disarm ΔP, PSI	Disarm Knots
2009	1.45	246	0.87	192	1.98	290	0.97	203
2010	1.52	253	0.95	201	2.37	313	1.20	225
2011	1.43	245	0.92	197	1.80	276	1.02	208
2012	1.47	248	0.95	201	1.64	263	0.85	185
2013	1.53	254	0.98	205	1.65	264	0.90	195
2014					2.22	305	1.20	225
2015					1.87	281	1.29	233
2016	1.41	244	0.97	204	1.92	285	1.00	206
2017	1.40	243	0.94	200	2.01	292	0.93	199
2018	1.50	252	1.25	230	2.42	317	1.37	240
2019	1.20	226	0.74	177	2.06	295	1.06	212
2020	1.45	247	1.01	207	2.40	316	1.14	220
2021	1.36	239	0.89	194	2.16	301	1.12	217
2022	1.38	242	0.90	195	2.28	308	1.28	232
2023	1.50	252	0.87	192	1.66	264	0.78	183
2024	1.35	238	0.95	201	1.96	287	0.98	204
2025	1.35	238	0.94	200	2.30	310	1.28	232
2026	1.41	244	0.81	185	1.91	284	1.08	214
2027	1.29	234	0.83	188	2.18	302	1.03	209
2028	1.50	252	1.01	207	1.86	280	1.08	214
2029	1.37	240	0.92	197	2.09	297	0.92	197
2030	1.20	225	0.90	195	1.65	264	1.06	212
2031	1.40	243	0.97	204	1.84	279	1.09	215
2032	1.55	256	0.79	183	1.96	287	0.86	191

Table 9

PHASE IIB LAUNCHER S&A TESTING

Test Type	No. Missions	No. Passed	Remarks
Field Test Ground Launcher	39	35	Total failures: 4 2 failures, mode 1 2 failures, mode 2
Field Test Aircraft Launched	61	48	Total failures: 7 1 failure, mode 2 1 failure, mode 3 10 failures, mode 4 1 failure, mode 5
	No. Units	No. Passed	
Laboratory System Tests	2	2	Units operated normally after all system test environments.

Definitions

No. Missions: The number of times S&A's were called upon to fire in either single or ripple mode.

No. Passed: The number of times S&A's armed, fired as selected, and disarmed after the mission.

Failure Mode 1: Failure to fire a rocket in the ripple mode traced to plume effects on the turbine and actuator assys.

Failure Mode 2: Failure to disarm after firing one or more rockets traced to conditions in the aft casting which caused rotor binding.

Failure Mode 3: Failure to maintain armed condition in flight traced to fairing fragments in turbine.

Failure Mode 4: Failure to disarm after firing one or more rockets traced to actuator bindings from multiple reuse.

Failure Mode 5: Destruction of the arming indicator disc due to improper shaft seal installation.

Table 10

DESIGN CHANGES IN PHASE III S&A'S

a. The actuator spline was pinned rather than friction fit to the actuator shaft to prevent its turning on the shaft.

b. The powdered metal balance ring was replaced with a machined steel ring to prevent breakage.

c. A positive stop pin was added to the rotor to prevent overtravel.

d. Holes were drilled in the actuator slide to relieve pressure effects of the plume.

e. An unnecessary section of the inertial lock hole was removed from the MDF block to prevent rotor binding after firing.

f. The forward facing inertial lock and its associated counterbore were removed from the forward rotor thrust face to prevent embossing of the casting thrust face by the counterbore.

g. The "safe lock" was removed from the aft section to prevent failure due to improper defeat upon installation in the pod.

h. Rotor contact configuration was changed to provide greater contact separation. This was necessary to eliminate the possibilities of shorting due to metallic debris from detonation.

i. A Rulon "J" seal ring was substituted for the metal rotor seal ring (piston ring) to give better seal characteristics and less impedance to rotor motion.

j. The casting material for all housing components was changed from A-364 to A-380, as the A-364 caused excess die contamination.

k. Tap-lock screw thread inserts replaced the helicoil inserts in all applications, as trouble with retaining the helicoils in the threaded holes was experienced in manufacture.

l. The actuator spring was shimmed to insure its correct preload and hence attempt to hold the arming and disarming speeds to a closer tolerance.

Table 11

PHASE IV POST-ENVIRONMENTAL ARMING, DISARMING AND RESISTANCE DATA

Serial Number	Acceptance Tests	Post Environmental Tests	Detonator Number Det. Res./Insl. Res. (ohms)				Remarks
	Arm/Disarm (psid)		1	2	3	4	
3055	1.46/1.10	1.99/1.43	1.4/OK	1.4/OK	1.4/OK	1.4/OK	
3070	1.16/ .86	1.34/ .84	1.3/OK	1.3/OK	1.3/OK	1.2/OK	
3072	1.18/ .88	1.33/ .86	1.1/OK	1.1/OK	1.4/OK	1.2/OK	No circuit on #4 for a moment after arming.
3073	1.16/ .80	1.21/ .86	1.3/OK	1.1/OK	1.2/OK	1.1/OK	
3074	1.22/ .88	1.39/ .89	1.3/OK	1.4/OK	1.4/OK	1.3/OK	
3075	1.38/ .94	1.61/1.11 1.33/ .97	1.1/OK	1.3/OK	1.1/OK	1.2/OK	Arm/Disarm values after disassembly & reassembly of aft section.

Table 12

PHASE IV LABORATORY ARMING, FIRING, AND DISARMING TEST RESULTS

Serial Number	Arm/Disarm Point (psid)	Detonator Fired	Input Current (amperes)	Remarks
3055	1.52/1.04	2	2.3	
	1.54/X	3	2.3	
	1.58/X	1,4	2.3	Three pulses required to fire det #4.
3075	1.07/X	2,4,3	2.3	Several pulses required to fire det #3, det #1 would not fire.
	1.30/X	1	2.7	
3072	1.13/.71	3	2.3	
	1.14/.74	2,4	2.3	Several pulses required to fire dets #2 and #4 - det #1 would not fire.
	1.18/NO	1	2.7	Two pulses required Rulon "J" seal jammed w/Ni plate and debris.
3074	1.12/X	2,4,3,1	2.7	
3070	1.19/X	2,4,3,1	2.7	
3073	1.01/.64	3	2.7	
	1.06/.71	1	2.7	
	1.06/X	2,4	2.7	Several pulses required to fire det #4.
3087	1.26/NO	2,4,3,1	2.9	Rulon "J" seal installed inverted.
3098	1.13/NO	2	2.9	Rulon "J" seal installed inverted.
	1.12/NO	4	2.9	
	1.42/NO	3	2.9	
	1.46/NO	1	2.9	
3089	1.03/NO	2,4,3,1	2.9	Rulon "J" seal installed inverted.

"X" denotes that disarm occurred, but pressure differential was not recorded.

Table 13

PHASE IV DISASSEMBLY INSPECTION RESULTS

Ser. No.	Use	Condition of the Turbine Section			Condition of the Aft Section		
		Turbine Bearing	Flyweight Bearing	Actuator Bearing	Rotor Housing Debris	Rotor	Rulon "J" Seal
3002	VX-5	OK	OK	OK	Nickel plate	Plating flaked	OK
3003	VX-5	OK	OK	OK	OK	OK	OK
3004	VX-5	OK	OK	OK	Nickel plate	Plating flaked	OK
3005	VX-5	Stiff	Two stiff 1 frozen	Frozen	OK	Rust through plating	OK
3031	VX-5	Very stiff	Stiff	Frozen	Nickel plate	Plating flaked	OK
3032	VX-5	OK	Stiff	Frozen	Nickel plate	Rusted	OK
3034	VX-5	Stiff	OK	Stiff	OK	OK	OK
3035	VX-5	OK	OK	OK	Nickel plate	Plating flaked	OK
3036	VX-5	OK	OK	OK	OK	OK	OK
3055	Lab test	OK	OK	OK	Nickel plate	Plating flaked	OK
3070	Lab test	OK	OK	OK	Nickel plate	Plating flaked	Rulon "J" seal jammed w/plating and debris
3072	Lab test	OK	OK	OK	Nickel plate	Plating flaked	OK
3073	Lab test	OK	OK	OK	OK	OK	OK
3074	Lab test	OK	OK	OK	OK	OK	OK
3075	Lab test	OK	OK	OK	Nickel plate	Plating flaked	OK
3087	Lab test	OK	OK	OK	OK	OK	Inverted
3089	Lab test	OK	OK	OK	Nickel plate	Plating flaked	Inverted
3098	Lab test	Used 3075 Turbine Section. 3098 Turbine destroyed in previous testing.			Nickel plate	Plating flaked	Inverted

APPENDIX A

A-1. Table A-1 contains the description, specifications, and requirements for the ZAP launcher S&A device as found in the specifications section of contract number N60921-68-C-0205. These are the conditions by which The Marquardt Corporation designed and built the MLU-53/B Launcher Safety and Arming Device.

Table A-1

DESCRIPTION, SPECIFICATIONS, AND REQUIREMENTS
FOR THE SAFETY AND ARMING DEVICE

INTRODUCTION

The safety and arming (S&A) device will be a high-speed, airflow spin device to be used in a new rocket and launcher system for jet aircraft.

DESIGN OBJECTIVES

The S&A device shall be a high-speed, airflow device that can operate for a minimum of 20 hours at speeds up to 600 knots in standard air between sea level and 15,000 feet.

The device must not be larger than 2.750 inches in diameter.

The contractor may choose to use a governor in order to meet the operational requirements herein; however, a governor is not a requirement for this device.

At the speed of 250 ± 25 knots, the device must have the capability of rotating a rotor 45° and closing a centrifugal switch to the rocket firing circuit.

When the speed is reduced to 200 knots (anywhere from 225 to 200 knots) and less, it must open the same centrifugal switch and the rotor must return to its original position.

The rotor will house four electrical explosive detonators spaced 90° apart. The rotor will be made of aluminum and will be less than 2.750 inches in diameter and 1.000 inches in width.

The detonator is approximately 0.275 inch in diameter and 0.500 inch in length. The detonators will have lead wires which must be able to be connected to a connector in the rocket firing system in the launcher.

When armed, the rotor with the detonator must align various explosive elements.

The rotor must meet the requirements of 2.5 above even if one or more of the detonators have been fired.

The centrifugal switch will carry a 28 VDC 10 amp and must be able to carry this current for a minimum of two seconds.

REQUIREMENTS

The spin device shall be rugged in construction and highly reliable in performance and must meet the following Navy safety and environmental requirements during Navy conducted test at NOL.

Table A-1

DESCRIPTION, SPECIFICATIONS, AND REQUIREMENTS
FOR THE SAFETY AND ARMING DEVICE (Cont'd)

Jolt test as specified in MIL-STD-331, Test No. 101.

Out-of-line safety test at NOL.

Salt spray fog as specified in MIL-STD-331, Test No. 107.

Temperature and humidity test 28 days as specified in MIL-STD-331, Test No. 105.

-65°F. Operational Test.

160°F. Operational Test.

Wind tunnel operational test at NOL.

Transportation vibration as specified in MIL-STD-331, Test No. 104, Procedure II.

Catapult launch and arrest landing as specified in MIL-STD-331, Test No. 212.

Vibration

The test unit shall be rigidly attached to the vibrator table with a fixture that transmits the desired vibration without introducing unrealistic resonances or restrictions that could keep the unit from vibrating in its normal modes. Simple harmonic vibration excitation is applied over the frequency range from 5 to 2000 Hz as specified by Curve C, Figure 514-3 of MIL-STD-810A. The vibration excitation is applied along each of three mutually perpendicular axes for equal time periods of 30 minutes, giving a total test duration of 90 minutes.

Shock Safety Test

The test unit shall be rigidly attached to the carriage of a shock test machine. The unit shall be subjected to four separate shock pulses, each characterized by a rise time of from 1 to 3 ms and a total duration of 8 to 12 ms. The peak acceleration shall be 1,500g ± 150g. The four shock pulses shall be applied as follows:

a. one along the rotating axis of the S&A in the forward direction

b. one along the rotating axis of the S&A in the aft direction

c. one perpendicular to the above axis in a direction parallel to one of the supporting structures of the S&A

d. one perpendicular to the two axes directly above.

DESCRIPTION, SPECIFICATIONS, AND REQUIREMENTS
FOR THE SAFETY AND ARMING DEVICE (Cont'd)

At the conclusion of this test, the unit shall be in the mechanical and electrical state that corresponds to its normal safe unactuated condition.

System stockpile-to-target requirements 3.8, 3.4, 3.9, and 3.10 shall be performed sequentially.

APPENDIX B

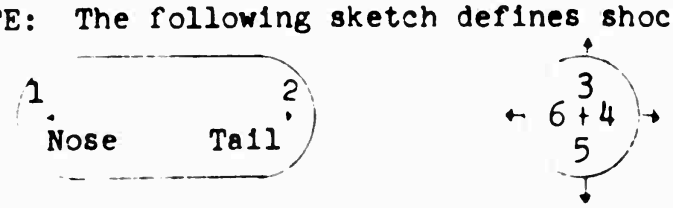
B-1. The environmental tests run on the ZAP Launcher S&A are described in Table B-1 of this appendix. Tests preceded by an asterisk (*) were devised specifically for the S&A device. All other tests were taken from NOLTR 68-9, "Test and Evaluation Plan for ZAP," Appendix B, to which the reader is referred for an amplified explanation of testing purpose and philosophy.

Table B-1

ENVIRONMENTAL TEST DESCRIPTIONS

Test	Test Code	Parameters
Low Frequency Vibration Level 2	LF Vib-2	0.1" from 10 to 20 Hz and 2.0g peak from 20 to 60 Hz. 4 hrs in each of 3 mutually perpendicular axes.
High Frequency Vibration	HF Vib	0.2" from 5 to 10 Hz, 1.0g peak from 10 to 18 Hz, 0.06" from 18 to 57 Hz and 10.0g peak from 57 to 2000 Hz.
Random Vibration Level 2	Ra Vib-2	10-2000 Hz at $0.05g^2/Hz$ (10g rms) for 10 min. Increase level to $0.15g^2/Hz$ (18g rms) for 10 sec. Conduct total test in each of 3 mutually perpendicular axes.
Shipboard Shock (Carrier) Level 2	SB Sh-2	125g peak, 5 ms duration, 10 fps velocity change, directions 1 to 6.
Catapult Acceleration Level 2	CAT-Acc-2	Axial: 15g peak, 0.4 sec duration, direction 2. Transverse: 5g peak, 0.4 sec duration, directions 3-6.
Arrested Landing Deceleration Level 2	Ar Dec-2	Axial: 15g peak, 0.4 sec duration, direction 1. Transverse: 12g peak, 0.4 sec duration, directions 3-6.
Jolt	--	1750 jolts in each of three mutually perpendicular axes as per MIL-STD-331, Test 101.
Forty-Foot Guided Drop	--	Mount the test item in a carriage which is guided throughout the 40-foot fall (or equivalent velocity) to strike a steel anvil. The test item is positioned so that the axis most vulnerable to defeat is vertical. Other test items are dropped having different orientations of impact. Each test item is dropped only once.

NOTE: The following sketch defines shock directions.



Arrows indicate direction of inertia

Table B-1

ENVIRONMENTAL TEST DESCRIPTIONS (Cont'd)

Test	Test Code	Parameters
High Shock	--	1500g ± 150g peak, 20 to 25 ms duration, 4 to 6 ms rise time, directions 1 through 4 (see note).
*Inertial Lock Shock Study	--	A study at various shock levels to determine the sensitivity of the inertial lock to shock.
*Captive Flight	--	Instrumented flight with the S&A mounted in a pod or simulated pod to determine S&A operating parameters in actual flight.
*Life Test	--	Continuous operation of the S&A for an extend period (~40 hrs.).
*Pod Launch	--	Launching rockets with the S&A mounted in its operational position.
*Wind Tunnel Operation	--	Operation of the S&A mounted in a simulated launcher to determine operating parameters following a curve similar to Figure B-1.
*+160°F Functioning	--	Four hour soak at +160°F followed by Wind Tunnel Operation.
*-65°F Functioning	--	Four hour soak at -65°F followed by Wind Tunnel Operation.

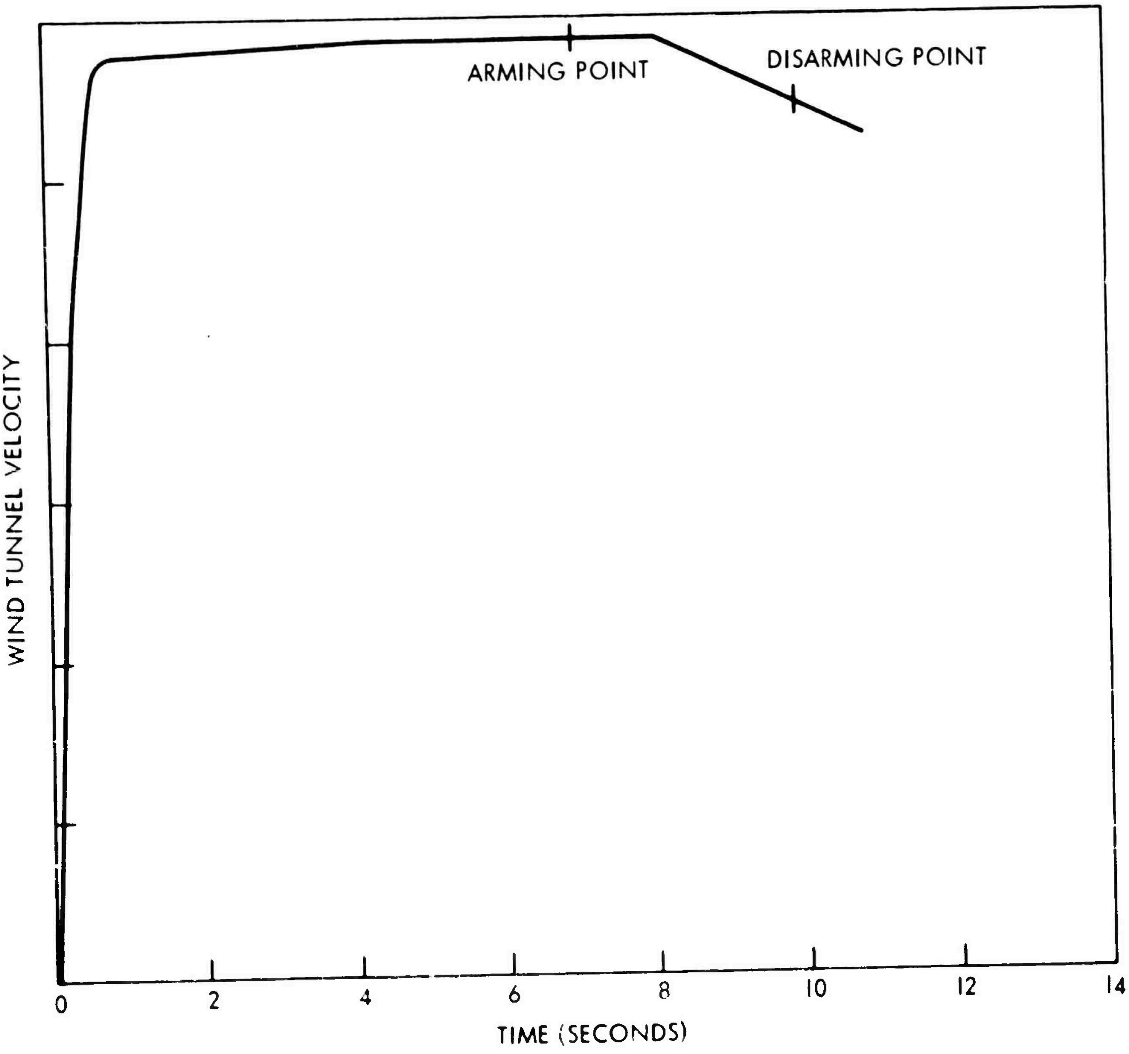


FIG. B-1 TYPICAL WIND TUNNEL VELOCITY VERSUS TIME CURVE FOR S&A OPERATION TESTS

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13. ABSTRACT
The Rocket Launcher Safety and Arming Device (S&A), MLU-53/B, was developed for use in the ZAP weapon system. The S&A program fell into four production/test and evaluation phases. Testing in each of these phases revealed weaknesses which were corrected in the next production phase. Because of tight schedules, weaknesses found in Phase III hardware, could not all be corrected in Phase IV production. These changes were approximated by the U. S. Naval Ordnance Laboratory, White Oak, on the Phase IV hardware. The limited Phase IV (OPEVAL) testing done indicated that the MLU-53/B S&A device was a workable item which represented a quantum step toward a safer air launched weapon system.

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